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TECHNICAL REPORT
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SEE-THROUGH TURRET VISUALIZATION PROGRAM

by

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14. ABSTRACT
A combat vehicle visualization system was developed to enhance situational awareness of a vehicle commander. The system has a 360° panoramic sensor, gimbaled infrared sensor, and helmet-mounted display (HMD). The HMD-displayed sensor data can aid the commander in vehicle maneuvering and threat acquisition while the vehicle is buttoned up. The HMD-displayed Force XXI Battle Command Brigade and Below (FBCB2) information can aid the commander in receiving orders and sending situationreports while standing in the hatch. A system requirements document based on interviews with armored vehicle commanders was created. Trade studies were performed to arrive at a system approach to meet the established requirements. Next, a development specification was created for a prototype system using existing sensor and display components to demonstrate the system features. A prototype system was assembled and demonstrated on a High Mobility Multipurpose Wheeled Vehicle (HMMWV). It was also exhibited at the CY2000 Fort Knox Armor Conference and the CY2000 AUSA show. The results show the system can providethe sensor and FBCB2 information required by the commander, and is robust enough tested on moving armored vehicles. Adeployable system can enhance a commander's performance on armored vehicles (Abrams, Bradley, Future Combat System (FCS)).

15. SUBJECT TERMS

COMBAT VEHICLES	HELMET MOUNTED DISPLAYS	PROTOTYPE SYSTEM	IMAGE PROCESSORS
HEAD TRACKERS	SITUATION AWARENESS	PANORAMIC SENSORS	TURRET
WARFIGHTERS	VISUALIZATION SYSTEMS	DEPLOYABLE SYSTEMS	
360 DEGREES VIEWING	ARMORED VEHICLES	GIMBALED SENSORS	

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Preface

This report outlines the research undertaken by Honeywell, Inc., Sensor and Guidance Products, Minneapolis, MN and Sarnoff Corp., Princeton, NJ, under U.S. Army Contract DAAN02-98-C-4034, for the period June 1998 to December 2000.

This report describes the design of a combat vehicle visualization system that provides increased situation awareness to the vehicle commander while seated inside the vehicle or while standing in an open hatch. The system gives the vehicle commander the ability to:

1) detect terrain hazards in the vehicle's path to aid the driver in recognizing hazardous situations that might immobilize the vehicle or cause damage to the vehicle and its crew,
2) detect nearby friendly forces and environmental structures to coordinate movement with other vehicles and to avoid damage to the vehicle, nearby friendly forces, or man made structures,
3) detect nearby ground threats to allow protective responses to be employed,
4) view imagery from the commander's independent viewer while standing in the open hatch,
5) view information on the commander's tactical display while standing in an open hatch to allow immediate notification of incoming reports and to assist in the preparation of outgoing reports without the need to duck back into the vehicle,
6) view Unmanned Aerial Vehicle (UAV) reconnaissance imagery while seated inside the vehicle or while standing in an open hatch.

The system can also be used by a squad leader in the vehicle's passenger compartment as a reconnoitering aid prior to exiting the vehicle for dismounted operations. These capabilities are especially useful at night when the enemy is in the vicinity and when direct vision is impaired because vehicle hatches must be buttoned up and vision blocks must be covered to avoid detection.

The report describes a prototype system that demonstrates essential system features using existing components to reduce development cost. Improvements envisioned for a deployable system are discussed. Finally, vehicle insertion opportunities are identified.

Acknowledgements

The authors wish to thank Mr. Henry Girolamo of the U. S. Army Soldier System Center and Mr. Norm Whitaker of DARPA/ATO for sponsoring this work under the DARPA Warfighter Visualization program. This work was performed under U. S. Army contract DAAN02-98-C-4034, "See-Through Turret Visualization System".

SEE-THROUGH TURRET VISUALIZATION PROGRAM

1.0 Introduction

The See-Through Turret Visualization (STTV) program is a Defense Advanced Research Projects Agency (DARPA) -funded research effort contracted through the U. S. Army Soldier Systems Center at Natick, Massachussetts. It was proposed in response to DARPA BAA 96-37, Warfighter Visualization, dated 15 November 96. A major goal of this Broad Agency Announcement (BAA) was "to enhance individual warfighter situation awareness and decision making ability by providing unique ways of receiving and interacting with spatially correct, timely information in both individually served and shared environments." Areas of interest identified in the BAA were: "I. Visually Coupled Systems, ...e.g., head-mounted displays and displays that allow users to see through physical barriers such as the hull of tanks..., and III. Enhanced Human Interface Technologies, ...e.g., high resolution wide field-of-view systems, and systems for the collection, fusion, and display of data containing large dynamic ranges in luminance and contrast...." It was further specified that "All contractors are encouraged to have direct interaction with operational forces during the design and development process. All systems should be demonstrated in at least one end product that functions in an operational environment. These products will be integrated into Warfighter Visualization demonstrations which will be conducted with a military customer. Selected applications are expected to include: ...tank/armored vehicle...and a dismounted warrior... Approaches that provide demonstration plans are strongly encouraged."

The objective of the See-Through Turret Visualization program is to enhance the situation awareness of armored vehicle commanders by providing a visualization system consisting of a 360° field-of-view panoramic image sensor, an image processor, and a helmet-mounted display with head tracker. The visualization system allows commanders to view the situation awareness data from a Force XXI Battle Command Brigade and Below (FBCB2) terminal while standing in the hatch, a vantage point which is used by most commanders when not engaging the enemy, but one which obscures the view of the FBCB2 display inside the vehicle. When engaging the enemy, the panoramic sensor allows commanders effectively to see through the vehicle's hull and to view the surrounding terrain on the helmet-mounted display. Panning around the vehicle is achieved naturally via the head-tracked sensor, leaving hands free for other duties. The image processor removes the image warping generated by the wide field-of-view camera lenses, merges the outputs of multiple cameras into a single seamless wide field-of-view image, and fuses the imagery from two different sensors to provide the commander an enhanced awareness of the vehicle's surroundings. The commander's helmet-mounted display was chosen to be identical to the dismounted soldier's helmet-mounted display being developed under the Army's Land Warrior program to achieve reduced system, logistics, and maintenance costs.

The See-Through Turret Visualization program capitalized on a long history of Honeywell efforts to provide a helmet-mounted display for armored vehicles. In October 1985, Honeywell and the U. S. Army evaluated a monocular see-through Integrated Helmet And Digital Display

System (IHADSS) type helmet-mounted display on an M1A1 tank at Fort Knox (Figure 1). The display viewed live Commander's Independent Thermal Viewer (CITV) imagery and situation awareness data from a Battle Management System developed by Lockheed. Excellent results were obtained, and participating tank commanders liked the system. The display was later exhibited on an M1A1 tank at the Fort Knox Armor conference along with a mockup of a productized version. In August 1992, Honeywell began the development of a new helmet-mounted display for armored vehicles under a DARPA-funded contract administered by the U. S. Army Soldier Systems Center at Natick, Massachusetts (contract DAAK60-92-C-0065, titled Combat Vehicle Crew (CVC) Helmet-Mounted Display). The display was a biocular see-through 640 x 480 pixel head-mounted display built into the tank commander's goggles (Figure 2). The display was subsequently evaluated by the Army's Mounted Warfare Battle Lab in the Distributed Interactive Simulation Facility at Fort Knox under an Army-funded contract administered by the U. S. Army Soldier Systems Center (contract DAAK60-94-C-2021, titled Enhanced User Evaluation and Demonstration of the CVC HMD). Two evaluations were performed in June 1994 and February 1995 using simulated CITV and Inter Vehicular Information System (IVIS) display screens developed with the assistance of General Dynamics Land Systems. The screens were displayed to Army user juries via the Simulation Network (SIMNET) and the CVC display. A hand controller was also used but no head tracker. It was concluded that the helmet-mounted display improved the commander's performance in real battle scenarios with no task or information overload. Tank commanders on the user jury volunteered that "we need this HMD." In July 1995 and again in August 1996, evaluations of the CVC HMD with vehicle motion were performed using the Crewman's Associate Ride Motion Simulator at the Tank Automotive Research Development and Engineering Center (TARDEC). The conclusion was that the helmet-mounted display performed well on a moving vehicle as long as it was sufficiently stabilized relative to the head. The groundwork was thus prepared for testing a helmet-mounted display on a moving M1A2 tank.

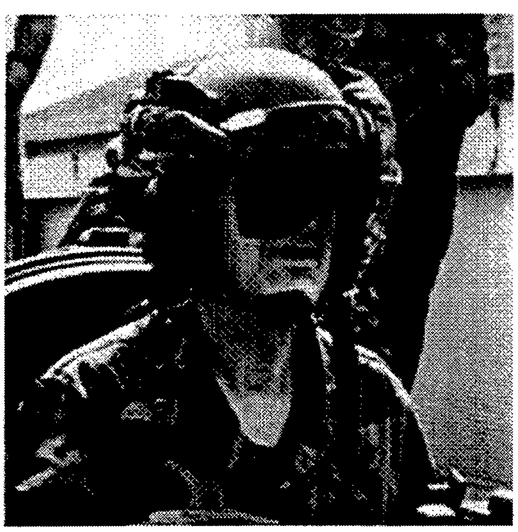


Figure 1. Honeywell CVC helmet-mounted display evaluated in 1985

Figure 2. Honeywell CVC helmet-mounted display evaluated in 1994-95

The See-Through Turret Visualization program was awarded to Honeywell on 18 June 1998. It was conceived as an evaluation of a helmet-mounted display on a moving M1A2 tank. The

program was planned as a four-phase effort. Phase I addressed concept development, Phase II preliminary system design, Phase III detailed system design, and Phase IV system integration and demonstration. Phase I included the development of a System Requirements Specification and a Prototype Development Specification for a prototype visualization system. Phases II and III addressed the design of the prototype system, and Phase IV addressed the fabrication of the hardware and software, its integration into an M1A2 tank or other surrogate vehicle, and its evaluation on the moving vehicle. In early 1999 it became apparent that DARPA would be able to provide only about half of the funding required to complete the full program. Therefore, it was agreed to eliminate the vehicle integration and moving vehicle evaluation tasks in Phase IV, and to address only the laboratory evaluation and demonstration of the prototype system. The following sections describe the work performed on these tasks and the results achieved.

Section 2.0 describes the methods, assumptions, and procedures used in the program. Section 3.0 summarizes the results obtained. These include the results of a user needs survey (Section 3.1), a system requirements specification (Section 3.2), trade studies to define a prototype development system (Section 3.3), a prototype development specification (Section 3.4), a description of the prototype system developed (Section 3.5), and system demonstrations performed (Section 3.6). Section 4.0 describes the conclusions obtained. One conclusion is that the prototype system is representative of a final deployable system and is sufficiently robust to support further evaluation of its effectiveness on a moving armored vehicle. A second conclusion is that the display alone, without a sensor, processor, or head tracker, can improve the performance of the armored vehicle commander. Section 5.0 describes some recommendations for further work, which include testing of the prototype system on a moving armored vehicle and development of a fully deployable sensor, helmet-mounted display, and head tracker.

2.0 Methods, Assumptions, and Procedures

The following methodology was used to develop the See-Through Turret Visualization System described in this report. First, a survey of user needs was performed to understand the system requirements. Interviews were conducted with U. S. Army tank commanders at the U. S. Army Armor Center at Fort Knox. Physical inspections of armored vehicles were performed at several sites, and an extensive review of the existing literature was made. Next, a System Requirements Specification was written to document the needs of an armored vehicle commander for situation awareness information. Trade studies were then performed to define a visualization system that would satisfy the system requirements. Trade studies addressed sensor performance, helmet-mounted display capabilities, head tracker availability, demonstration vehicle selection, and vehicle interfaces. Next, a hypothetical deployable visualization system was conceived that was capable of meeting the specified requirements. This visualization system involved sensors, processors, helmet-mounted displays and head trackers whose performance exceeded what was available during the time frame of the program. Next, a prototype of the hypothetical system was defined that could demonstrate the essential system operation in a timely fashion using existing components to minimize program cost, although at the expense of ultimate performance. A Prototype Development Specification was then created to describe the prototype demonstration system. Next, the prototype system was designed and fabricated. Finally, the prototype system was evaluated in the laboratory and on a stationary HMWWV vehicle. User demonstrations were also carried out at the Fort Knox Armor Conference and the Association of the United States Army (AUSA) show in Washington, D. C.

It has been assumed that the See-Through Turret Visualization program addresses the situation awareness needs of the armored vehicle commander only, and not the needs of the driver, gunner, loader, or passengers. However, it does address the situation awareness needs of a squad leader in an armored personnel carrier, such as an M2A3 Bradley, where the squad leader needs much of the same situation awareness information as the vehicle commander before dismounting from the vehicle on a mission. This includes mission data from the FBCB2 system and a view of the terrain surrounding the vehicle to locate immediate threats for avoidance or neutralization.

3.0 Results and Discussion

3.1 User Needs Survey

A survey of user needs was performed to understand armored vehicles and the requirements of vehicle commanders for situation awareness information. The survey included detailed interviews with U. S. Army tank commanders at the Fort Knox Armor School, physical inspections of armored vehicles at several sites, and an extensive review of the existing literature.

Interviews were conducted with U. S. Army tank commanders during visits to the U. S. Army Armor Center at Fort Knox on 26, 27 August 1998 and 9 September 1998. The half-day interviews involved two M1A1 and M1A2 tank commanders who were also instructors of tank commanders at the U. S. Army Armor School. The information they provided correlated well with interviews held with five U. S. Army M1A1 commanders who served as jurists during a previous Army contract (contract DAAK60-94-C-2021, titled Enhanced User Evaluation and Demonstration of the CVC HMD). It also correlated well with interviews held with two U. S. Army M1A1 commanders who evaluated Honeywell's first CVC helmet-mounted display on 8 and 9 October 1985.

Interviews were conducted with U. S. Army Bradley commanders during a Bradley Fire Support Team (BFIST) vehicle demonstration of the Land Warrior display at Fort Sill on 16 June 1997. Additional interviews were conducted during user tests of a helmet-mounted display on a Bradley M2A3 sponsored by the Bradley program office. These tests consisted of an organizational meeting on 23 September 1998, and a Limited User Test at Yuma, Arizona, on 19 November 1998. These interviews provided much the same information on situation awareness needs as the interviews with the Abrams tank commanders.

Physical inspections of an M1A2 Abrams tank were performed at Fort Knox on 26, 27 August 1998 and 8 September 1998 (Figure 3), and at Aberdeen, Maryland on 16 April 1999. The inspections consisted of climbing inside and outside the vehicle; trying out all the possible positions assumable by the various crew members and noting their respective displays, controls, and sight lines outside the vehicle; trying out the various hatch positions; taking photographs of the inside and outside of the vehicle; making detailed measurements of critical dimensions; and witnessing the operation of the CITV Forward-Looking Infrared Sensor (FLIR). The inspection on 8 September 1998 included a ride in a moving M1A2 (Figure 4), which allowed observing the commander perform his duties and experiencing tank motion dynamics from the commander's station and the gunner's seat.

Physical inspection of a Bradley BFIST was performed at Fort Sill in June 1997. Additional inspections of Bradley M2A2's and Bradley M2A3's were performed at United Defense Limited Partnership (UDLP) in San Jose, California, on 13 October 1998, and during an FBCB2 Limited User Test at Yuma, Arizona, on 19 November 1998 (Figure 5). The inspection on 19 November 1998 included a ride in a moving Bradley M2A2, with the opportunity to observe the commander's tasks and to experience motion dynamics from the passenger and commander's positions. Physical inspections of an M113 were performed at the Minnesota National Guard in

New Brighton, Minnesota, on 14 October 1998 (Figure 6) and again on November 1998. Information similar to that described earlier for the Abrams tank was obtained.

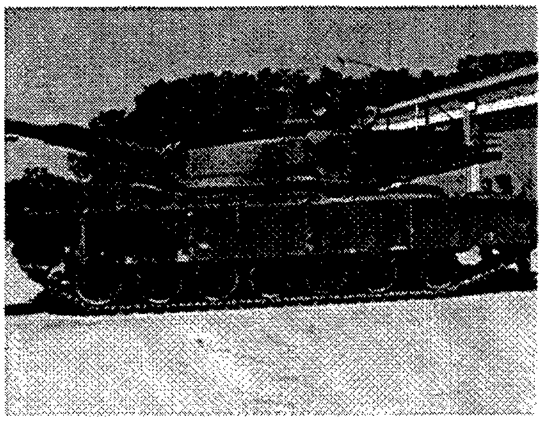


Figure 3. M1A1 at Fort Knox 26 Aug 98

Figure 4. M1A1 at Fort Knox 8 Sep 98

Figure 5. Bradley at Yuma 19 Nov 98

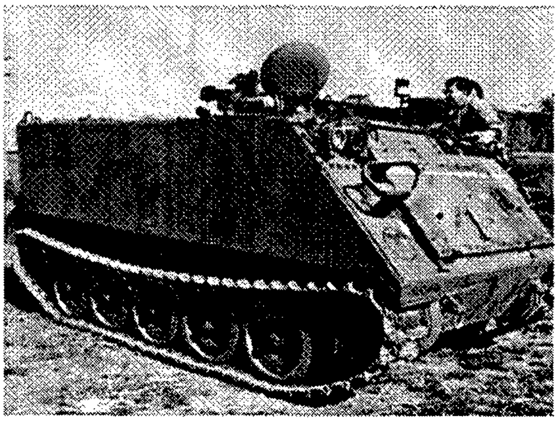


Figure 6. M113 at New Brighton 14 Oct 98

Readers interested in making their own physical inspections of an Abrams M1A2 and a Bradley M3A3 can do so by visiting the Army's web site at www.goarmy.com/tour/adv/tank.htm and www.goarmy.com/tour/adv/bradley.htm.

Further information on armored vehicles and the situation awareness needs of an armored vehicle commander was obtained from the following sources:

- contractor technical reports from the Combat Vehicle Crew (CVC) program,
- review of U. S. Army technical manuals describing the M1A2, M3A2, M2A2 ODS (Operation Desert Storm), and M113 Army vehicles,
- information from U. S. Army program offices, U. S. Army Battle Labs, and U. S. Army contractors available on the World Wide Web,
- information from U. S. Army program offices and U. S. Army government contractors provided at AUSA exhibitions,
- literature survey consisting of the last five years of articles from the following sources:
    - Jane's International Defense Review
    - Jane's Defense Weekly

- Jane's Defense Systems Modernization
- Armada
- Defense Week
- U. S. Army Times
- National Defense
- Society of Photo-Optical and Instrumentation Electronics (SPIE) papers
- Aviation Week and Space Technology
- Assorted books on armored vehicles:
    - M1 Abrams by Steve Zaloga and Peter Sarson (New Vanguard Series by Osprey Publishing Ltd. Great Britain)
    - M2 / M3 Bradley by Steve Zaloga and Peter Sarson (New Vanguard Series by Osprey Publishing Ltd, Great Britain)
    - Armored Cav: A Guided Tour of an Armored Cavalry Regiment by Tom Clancy (Berkeley Publications Group, USA)

• scale models of the M1A2, M2A2, and M113 Army vehicles.

Information relating to sensors and displays on armored vehicles was obtained from the above sources with the addition of the following material:

• information from sensor and display vendors available on the World Wide Web,

• literature survey consisting of the last five years of articles from the following sources:
- Unmanned Vehicles (Shephard Press)
- Defense Helicopter (Shephard Press)
- Helicopter World (Shephard Press)
- Interavia (Aerospace Media Publishing)
- Society for Information Display (SID) Proceedings.

Information from these sources was cross-correlated for accuracy and then published in an interim report for this program, dated December 1998. The following discussion summarizes the findings of this user needs survey.

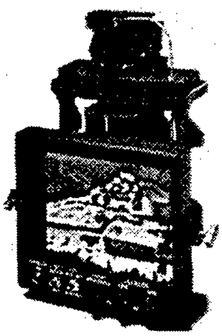
As a result of the U. S. Army's initiatives to "own the night" and to "increase the situation awareness of Army commanders" via networked battle management systems, the U. S. Army is adding to its armored vehicles a suite of electronic systems to enhance their lethality and survivability (Table 1). Some of these systems, such as the Driver's Vision Enhancer (Figure 7), the Gunner's primary sight, and the Battlefield Combat Identification System, give drivers and gunners more advanced tools for performing existing tasks. Other systems, such as the Commander's Independent Thermal Viewer, and the FBCB2 Tactical Terminal, give vehicle commanders entirely new tasks and capabilities. The commander's independent thermal viewer on the M1A2 Abrams, for example, allows the commander to hunt for new targets while the gunner is dispatching an existing target, a capability that was not present on the M1A1. While this provides up to a 60% improvement in the effective rate of fire, it may divert the commander's attention from other essential tasks such as vehicle navigation or vehicle communication. In this case the commander's heavy workload is further increased.

Another system that increases the vehicle commander's workload is the FXXI Battle Command Brigade and Below (FBCB2) tactical terminal. This networked computer system provides

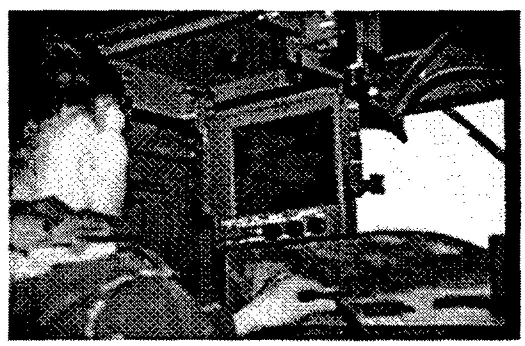
increased situation awareness in the form of rapid accessibility to enemy and friendly positions, topographical maps, commander's orders, situation reporting, and vehicle needs/status reporting. The situation awareness data allows the commander to make more informed and rapid decisions prior to and during an enemy encounter. But interaction with the digital terminal requires the commander to view the display inside the vehicle, while many of his other duties require his attention to be outside the vehicle.

Table 1. New and improved electronics for Army vehicles

Electronic System	Description	Use
Commander's Independent Viewer	8-12 micron 2nd generation FLIR sensor	Target hunting (Commander)
FBCB2 Tactical Terminal	Networked Appliqué or embedded computer	Situation awareness (Commander)
GPS Navigation System	Precision lightweight GPS receiver (PLGR)	Navigation (Cmdr & driver)
Driver's Vision Enhancer	8-12 micron uncooled infrared sensor	Terrain viewing (Driver)
Gunner's Primary Sight	8-12 micron 2nd generation FLIR sensor	Target sighting (Gunner)
Battlefield Combat ID System	Ka-band narrow beam interrogator plus omni-directional receiver / transponder	Friend/foe ID (Gunner)



(a) sensor and display



(b) installation in HMMWV

Figure 7. Driver's Vision Enhancer

The commander's workload is stressed the most in the case of turreted armored vehicles such as the Abrams and the Bradley. When not engaging the enemy, the vehicle commander is trained to stand in the hatch while the vehicle is moving and to search continuously for road hazards, ground-based threats, friendly forces, and other objects or situations that might affect his vehicle. He is constantly giving verbal commands over the vehicle's intercom system to tell the driver to turn right or left or the gunner to slew the turret right or left. While standing in the hatch he is unable to use the commander's independent thermal viewer (CITV) or the FBCB2 tactical terminal because their displays are viewable only while inside the turret. This makes it difficult

to prepare situation reports while maintaining outside awareness. It may even cause him to miss a critical communication from his commander.

When engaging the enemy and the vehicle is buttoned up, the situation is reversed. In this case, the CITV display and the FBCB2 tactical terminal are directly viewable, but the commander has little awareness of the vehicle's immediate surroundings or its turret-hull orientation. The commander's independent thermal viewer is excellent for acquiring targets at longer ranges, but its narrow field of view (13.3°x7.5° maximum) and limited slew rate (60°/sec) are not well matched to seeing threats at nearby ranges (≤ 400 meters). The commander's viewing ports are intended to provide such a capability, but are limited to visible light only and are frequently taped over at night to preclude the enemy from spotting the vehicle due to light emanating through the ports.

The vehicle commander's needs obtained in this survey are summarized in Figure 8. Basically, the vehicle commander needs a way to see the FBCB2 and CITV displays inside the vehicle when his head is outside the vehicle, and a way to see the vehicle's immediate surroundings outside while his head is inside the vehicle. It is frequently necessary for the commander to have his head outside the vehicle to search for airborne threats and threats in nearby tree lines, and to make sure that the vehicle does not get into compromising situations with terrain hazards or cause damage to nearby friendly vehicles, infantry, or man-made structures. Therefore, the commander is trained to keep his head outside of the vehicle at all times while it is moving except when he expects direct fire from the enemy. Specifically, he is taught that the only way to know the orientation of the vehicle's turret with respect to the hull is to have his head outside the vehicle and to observe directly the turret's orientation with respect to the hull or with respect to the ground moving by.

The needs encountered in this user survey have been documented in an official U. S. Army document entitled "User Functional Description accompanying the Force XXI Brigade and Below Operational Requirements Document, Version 5.2, Change 1, dated 23 July 99". In Appendix B of that document, titled Displays, it is stated that "a HMD is required so that the BC (Bradley Commander) will be provided with access to (FBCB2-provided) situational awareness while viewing outside the turret. It is required that the BC have situation awareness (e.g., Helmet Mounted Display) both inside the turret and while viewing outside the turret". Additional paragraphs document similar needs for the Abrams tank commander, the Bradley Linebacker commander, and the squad leader in the Bradley Fighting Vehicle.

Having established the situation awareness needs of the vehicle commander in terms of information, it is now possible to translate these needs into STTV system requirements by looking at the vehicle commander's sensors, displays, and interfaces. The sensors and displays available to the commander on the Abrams and the Bradley are shown in Table 2. Although the Abrams and Bradley displays differ noticeably in design, their performance characteristics are similar at any given time. Furthermore, as the vehicles are upgraded to newer models, the imaging sensors and situation awareness systems are upgraded to newer models as well. At any given time one may find in the field vehicles of all upgrade types. However, it is the Army's goal to eventually upgrade each vehicle to the latest standard shown in the right hand column of

Table 2. Therefore, it is safe to establish the STTV system requirements using the characteristics shown in the right hand column of Table 2.

- Provide the vehicle commander increased situation awareness of the vehicle's surroundings while inside the vehicle or while standing in an open hatch. This is needed for:
  - Detection of terrain hazards to help the commander aid the driver,
  - Detection of nearby friendly forces and environmental structures,
  - Detection of nearby ground threats,
  - Display of information from the commander's independent thermal viewer and tactical display,
  - Display of UAV imagery.
- Provide this increased situation awareness under day, night, and all-weather conditions when the commander's vision blocks must be covered and the vehicle's hatches must be buttoned up.

Figure 8. Vehicle commander's needs from user survey

3.2 System Requirements Specification

Based on the information collected in the user survey described in Section 3.1, a System Requirements Specification was developed. The specification describes the needs encountered in the user survey and postulates a system having a sensor, a helmet-mounted display, and a head tracker (Figure 9). The sensor is required when the system is deployed on a vehicle that lacks its own night vision sensor, such as an M113 or M1A1. It is also required on vehicles already having a commander's independent sensor because the slew rate of the existing sensor is too slow to match normal head motion (~150°/second required), and the field of view is too small to cover a large search area quickly. The required performance capabilities of the sensor, display, and situation awareness system are shown in Figure 10. The complete specification is included in Appendix 1 of this report.

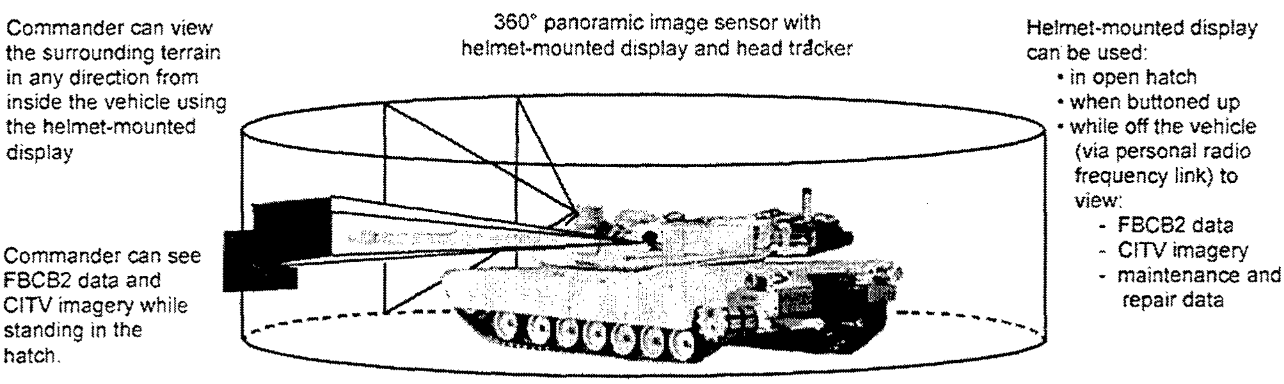
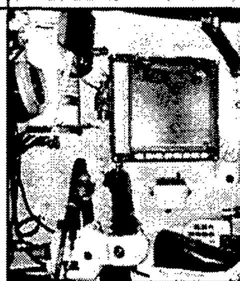
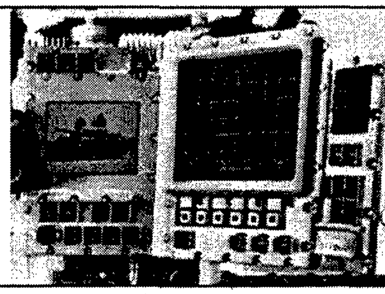
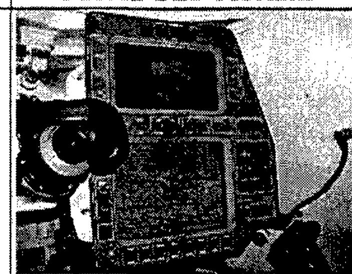
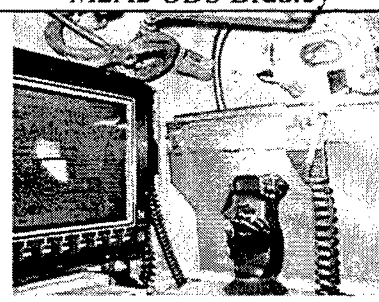
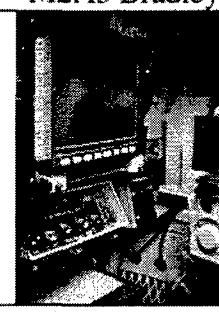


Figure 9. Envisioned see-through turret visualization system

Table 2. Commander's sensors and displays on the Abrams and the Bradley

Vehicle	M1A1-D Abrams	M1A2 Abrams		M1A2 SEP Abrams
Abrams Displays				
Vehicle	M2A2 Bradley	M2A2 ODS Bradley		M2A3 Bradley
Bradley Displays				
Imaging Sensor Characteristics	CWS 20°x15°(3X) day only	CITV 7.5°x15° (3X) WFOV 2.5°x5°(10X NFOV	CIV 3.4°x6.8°(2X) WFOV 1.1°x2.2°(6X) NFOV	CITV & CIV 13.3°x7.5° (3X,6X) WFOV 3.6°x2.0°(13X,25X,50X) NFOV
		1st gen FLIR 8-12 μm 0.1°C NETD no zoom tgt det & recog to ~2000 m 60°/sec slew rate continuous, preset, or manual rotation slew to cue function 4:3 aspect ratio RS-330 output		2nd gen FLIR 8-12 μm 0.01°C NETD 2x and 4x zoom tgt det & recog to ~4000 m 60°/sec slew rate continuous, preset, man rotation slew to cue function 16:9 and 4:3 aspect ratio modified RS-170 output
Imaging Display Characteristics	N/A	CID analog x 480 lines 4:3 aspect ratio square pixels monochrome		CDU 1316 x 480 pixels 16:9 aspect ratio non-square pixels* monochrome
Situation Awareness Display Characteristics	N/A	IVIS /Applique 640 x 480 (VGA) RS-170 output color		FBCB2 /Applique+ CIV & DVE also displayed 800 x 600 (SVGA) RS-170 output color

*special display required or warper required with 1:1 pixel display

Sensor Performance	Display Performance
• 360° field of regard • 40°x30° field of view • in focus ≥ 15 feet • 8-12 μm wavelength • ≥150°/sec slew rate	• monocular • non see-through • 800x600 pixels • 40°x30° field of view • color

System Performance

- able to detect human at 400 yards
- < 66 msec sytem latency
- slew to cue capability

Figure 10. Required system performance capabilities

Section 3.3 Trade Studies

Trade studies were conducted to arrive at a system design that provides the best possible response to the system requirements. Figure 11 lists the trade studies that were performed. Results are described in the following subsections.

- Sensor
  - Panoramic sensor approach
  - Camera type
  - Gimbaled sensor approach
  - Sensor resolution versus wavelength
- Helmet-mounted display
  - Monocular versus biocular approach
  - Color versus monochrome approach
  - Direct view versus see-through approach
  - Land Warrior compatibility approach
- Head tracker
- Demonstration vehicle
- Vehicle interface
  - Sensor location on M1A2
  - Controls on M1A2
  - Sensor location on M113

Figure 11. Trade studies conducted

3.3.1 Panoramic Sensor Approach Trade Study

This trade study considered panoramic sensor approaches as a means of addressing the system requirement for a 360° field of regard sensor. Panoramic sensor approaches were initially

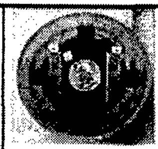
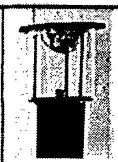
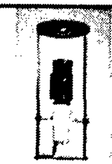
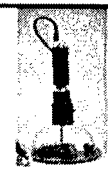
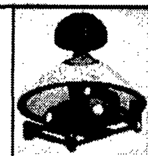
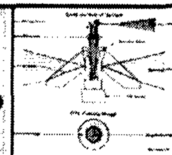
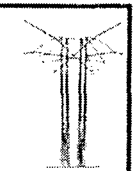
considered to be superior to scanned sensor approaches because of their lower latency when used with a head tracker. The trade study was limited to commercially available panoramic sensors because of the desire to conserve program funding.

Table 3 shows the ten different panoramic sensor approaches considered. These approaches represented all the commercially available panoramic sensor approaches available at the time the tradeoff study was performed. These approaches were evaluated relative to the following criteria:

1) field of regard
   a) azimuth field of regard
   b) elevation field of regard
2) sensor resolution
   a) number of cameras
   b) camera lens field of view
   c) pixels per camera
3) absence of parallax between adjacent cameras due to the physical displacement of the camera focal points
4) obscuration of the field of regard by required mounting hardware
5) ability to separate the unit into separate cameras to simplify mounting on multiple vehicles
6) modifications required to upgrade the sensor to 8-12 μm wavelength
7) relative size and
8) relative cost.

All of the single camera approaches were eliminated immediately because they lacked the resolution achievable by the multiple camera approaches, particularly in the vertical direction. The remaining multi-camera approaches were similar in their ability to achieve improved resolution and zero obscuration. The IPIX-like approach with its wide-angle fisheye lenses was preferred initially because of its small size, low cost, and potential ability to separate it into multiple cameras that could be distributed around the vehicle. Therefore, an IPIX-like approach using eight CCD cameras with 58° FOV lenses was selected in Phase I of the program for the baseline system design. However, during Phase II of the program, feedback from image processing engineers during the sensor design task noted that an IPIX-like approach, when scaled up to make use of commercially available cameras, produced a noticeable parallax between the images from two adjacent cameras. The parallax was caused by the physical separation of the focal points of the adjacent cameras, and led to similar objects in the adjacent images being displaced laterally by amounts proportional to the camera focal point separation and the range of the objects from the sensor. The variation of object displacement with range made it impossible to stitch together the images from adjacent cameras to produce a seamless 360° panoramic image. This parallax could be minimized to the point of being unnoticeable by using an IPIX-like approach with the camera separation kept small by camera miniaturization. However, this was not compatible with the use of commercially available low cost CCD cameras. Therefore, it was decided to use a PVSI-type approach with tilted mirrors along with off-the-shelf CCD cameras.

Table 3. Candidate panoramic sensor approaches

										
Company	IPIX	Panoram	PVSI	PVSI	Columbia	Columbia	Cyclovision	BeHere	Mitsubishi	NRC
Product	Omnicam	FullView	Multi-CCD	Single CCD	Omnivideo	Omnicamera	Paracam	Portal S1	---	---
Azimuth FOR	360°	360°	360°	360°	360°	360°	360°	360°	360°	360°
Elevation FOR	±55°	Adjustable	Adjustable	±22.5°	0/-90°	0/+90°	0/-90°	±50°	±40°	±20°
No. Cameras	4	4	4	1	1	1	1	1	1	1
Camera Lens FOV	105°	105°	105°	≤20°	≤20°	≤20°	≤20°	≤20°	≤20°	≤20°
Camera pixels	768x494	1600x480	2048x512	768x494	768x494	768x494	768x494	768x494	768x494	768x494
Adjacent Camera Parallax	Minimal (if small)	None	None	None	None	None	None	None	None	None
Obscuration	None	None	None	Struts	Struts	None	Struts	None	Struts	None
Ability to Separate	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
IR Compatiblty Modifications	Fisheye Lens	Cyl or Flat Windows	Cyl or Flat Windows	Cylind Window	Cylind Window	Hemispher Window	Cylind Window	Conical Window	Cylind Window	Custom Lens
Relative Size	Small	Large	Large	Medium	Medium	Medium	Medium	Medium	Small	Medium
Relative Cost	Medium	High	High	Low	Low	Low	Low	Low	Medium	Medium

3.3.2 Camera Wavelength/Resolution Trade Study

The choice of a PVSI-type approach with separate cameras gives one the flexibility to select the wavelength and resolution of the cameras to be used in the overall panoramic camera unit. Figure 12 shows the range of possible camera types plotted versus camera wavelength and resolution. Details of the cameras included in each of the ovals can be found in the Phase I interim report. Solid ovals represent classes of cameras already available while dotted ovals represent classes of cameras currently in development but available at the time of writing.

The system requirements suggest that the preferred camera approach should lie as close as possible to the upper right hand corner of Figure 12. This agrees with the selection by the U. S. Army of the Horizontal Technology Integration (HTI) second generation FLIR as the sensor of choice for its attack helicopters and armored vehicles. The next best sensor is a third generation staring HgCdTe FLIR, which is also currently in development. This sensor will not replace the HTI second generation FLIR, however, until its resolution can be improved to 2048x2048 pixels. All of the HgCdTe sensor approaches in Figure 12 are too expensive for the current STTV program, especially when it is considered that at least four sensors are needed to obtain a 360° field of regard using a panoramic camera approach.

This leaves one with the choice of using visible Charge Coupled Device (CCD) sensors or a lower resolution 8-12 μm infrared sensor. Since both high resolution and 8-12 μm infrared sensitivity are needed to meet the STTV system requirements, it was decided to use eight standard resolution visible cameras in the panoramic camera unit along with a ninth 8-12 μm infrared sensor in a scanned sensor unit that could be superimposed on the panoramic camera image. The sensors that were chosen, therefore, were eight 640x480 pixel CCD cameras for the panoramic camera unit and one 320x240 pixel microbolometer camera for the scanned camera unit.

3.3.3 Gimbaled Sensor Approach Trade Study

Having introduced the need for a scanned 8-12 μm infrared sensor, a second tradeoff study was conducted to find the best possible gimbaled sensor unit for the STTV program. This required finding both an IR camera and a gimbaled scanner that could be mounted on an armored vehicle. The STTV requirements in this case were very similar to the requirements for a payload sensor onboard a helicopter or unmanned aerial vehicle (UAV). The tradeoff study, therefore, considered all the possible gimbaled sensor payload packages that could be found onboard these vehicles.

Candidate gimbaled sensor approaches are shown in Table 4. This table represents the complete set of gimbaled sensor payload packages available at the time the trade study was performed (4Q98). Table 5 shows the leading candidates from Table 4 based on smallness of size and fast gimbal slew rate. The most attractive of these candidates for the STTV system, based on smallness of size, fast gimbal slew rate, and lowest cost, was the Nytech gimbal using a 320x240 pixel microbolometer sensor.

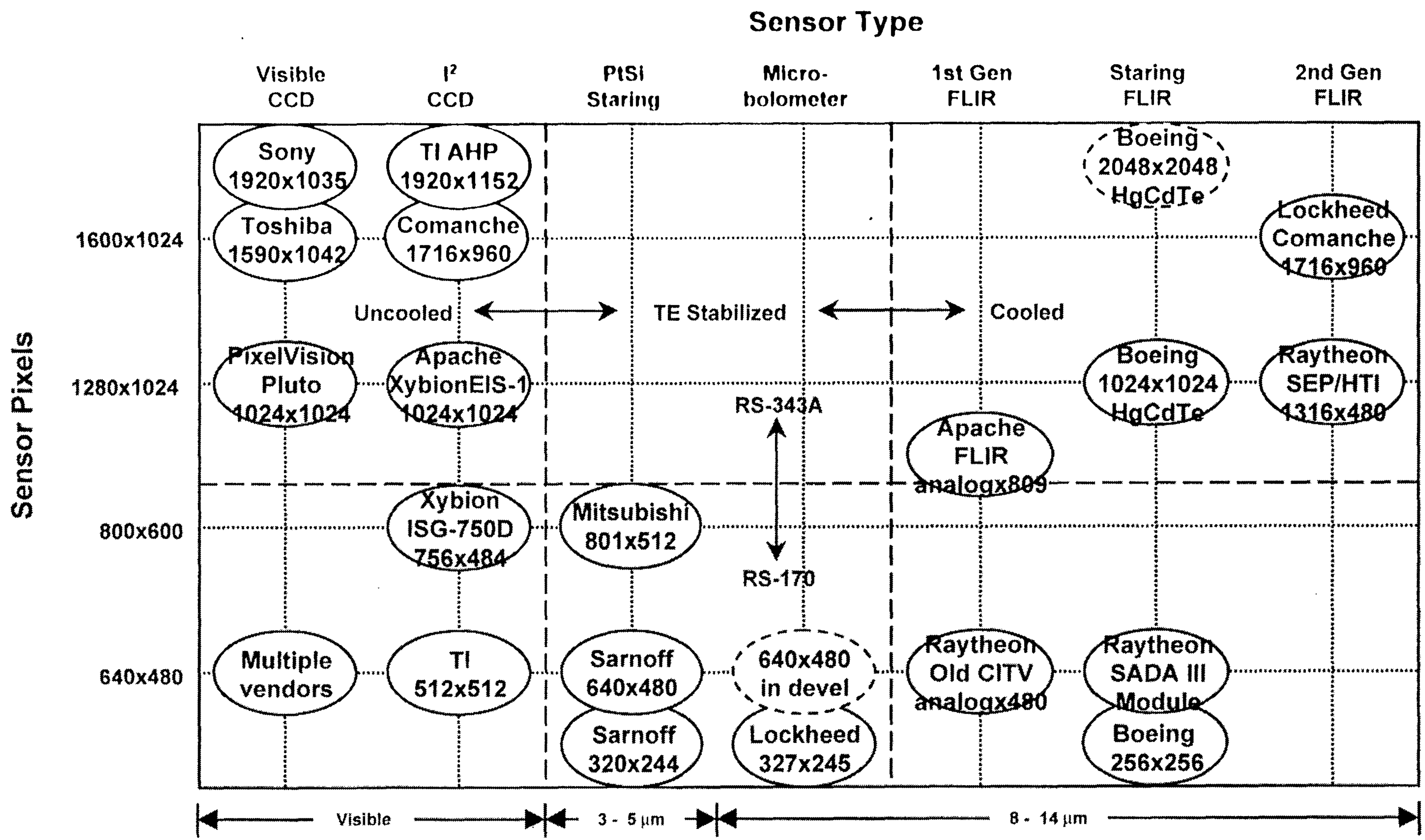


Figure 12. Candidate sensors versus wavelength and resolution

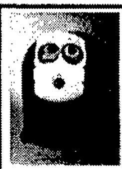
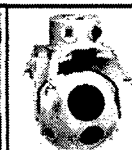
Table 4. Gimbaled sensor payloads

Payload Name	Mfgr	Gimbal Size (dia x ht)	Gimbal Weight (kg)	Gimbal Slew Rate	Gimbal Control Interface	Stabiliz	Sensors	Wave length	FOV	Pixels	Capabilities
HTVS DVE	Nytech G-210	10" dia 14.2" hi	25 lb +cams	200°/sec	RS-422	150 µm	µbolometer	8-12 µm	40°x30°	320x240	
TI FLIR-49 WRA-1 turret	Raytheon TI	12.8" dia 14.7" hi	57 lb	170°/sec	1553B		2nd gen FLIR	8-12 µm	30°x22.5° 6.67°x5° 1.7°x1.3°		2:1, 4:1 el zoom
HNVS Turret/FLIR unit	Raytheon Hughes	12 " dia 14 " hi	42 lb	170°/sec			FLIR	8-12 µm	40°x30° 1x to 6x 1x to 9x		
ASELFLIR-200	Aselscan (Turkey)	12" dia 13" dia w CCD		head steerable	1553B	Yes	FLIR Color CCD	8-12 µm visible	2X,4X zoom 3 FOV's		Tracker, frame freeze 240x4 array
Pioneer UAV LAV-25	WESCAM Model 12	12" dia 14.6" hi	23 kg	90°/sec	RS-422	35 µm 2 axis	InSb FLIR CCD	3-5 µm visible	25°x25° 14:1 zoom	256x256 480	5x zoom µbolometer avail
Predator UAV DarkHorsUCAV	WESCAM Model 14	14" dia 16.5" hi	34 kg	90°/sec	RS-422	35 µm 2 axis	PtSi or InSb Day CCD	3-5 µm visible	23°x17°	512x512 480	µbolometer avail 10x zoom QUIP used
Ultra 6000	FSI	11" dia 15" high	42 lb			4-axis	InSb FLIR Mono CCD	3-5 µm	20°,4° 5x zm 22°,15:1 zm		2X elect zoom NEΔT <0.030°C
AN/AAQ-22 Series 2000 FLIR	FSI SAFIRE	13" dia 19" hi				yes	FLIR CCD	8-12 µm or3-5 µm	28°, 7°, 5° 7.5°		
Ultra 4000	FSI					3-axis	FLIR CCD		28°, 7°, 5° 51°x40° 16:1		Tracker 2x extender
UltraMedia-RS	FSI	11" dia 14"hi	35 lb 75W				CCD only		40:1 zoom		
IRTV-445G	Inframetrics	9" dia ball	28 lb			2-axis	HgCdTe CCD	8-12 µm visible	19°x14°,12xz 24°x18°,7xz		NTSC or PAL
Outrider UAV	Tamam	10" dia 15" hi	16 kg 90W	60°/sec	RS-422	60 µm	FLIR CCD	visible			tracker
Pioneer UAV Hunter UAV	Tamam MOSP		24-38			25 mrad	FLIR TV	visible			
Pioneer UAV SPIRI²T	Tadiran MKD-400		20 kg				FLIR CCD LLTV	visible	2.4-15° 6.25:1 zoom	256x256	
Aquilla UAV NITE Eagle	Loral		32 kg	60°/sec			Raphael FLIR			120x1	

Table 4. Gimbaled sensor payloads (continued)

Payload Name	Mfgr	Gimbal Size (dia x ht)	Gimbal Weight (kg)	Gimbal Slew Rate	Gimbal Control Interface	Stabiliz	Sensors	Wave length	FOV	Pixels	Capabilities
SALS	Controp (Recon Optical)	Very small	3.8 kg 25W			50 µrad	Mono CCD	visible			Det truck@20km Rec truck@6km ID man@200m
ESP-60C	Controp (Recon Optical)	11.8" dia	26 kg			50 µrad	Mono CCD	visible	50-300mm 16mmWF OV		Day only
DSP-1	Controp (Recon Optical)	12.6" dia	26 kg		RS-422	yes	InSb FLIR Color CCD	3-5 µm visible	22.5x zoom 20X zoom		tracker
FSP-1	Controp	12.6" dia	26 kg		RS-422	yes	Color CCD	visible			
ESP-1H	Controp		8.7 kg								
Seeker UAV	Kentron						TIS Color CCD	visible			Rec 3m @ 7 km
NightSight 200W	Raytheon TI	12"x10" x10"	19 lb	45°/sec continuous		No	µbolometer	8-12 µm	12°x9°	320x164 320x240	det man @ 2400 ft RS-170
NightSight 4000	Raytheon TI	11"x9"x 9"	10 lb	45°/sec continuous		No	µbolometer	8-12 µm	12°x9°	160x120	det man @ 1500 ft RS-170
IRG-600	Sierra Pacific	7"x8"x8"	15 lbs			Yes	PtSi	1.2-5.9 µm		512x512	
AN/IR-360	Sierra Pacific			0-100°/sec		No	µbolometer	8-12 µm	12°x9°	320x240	det man @ 500 m RS-170
	Lockheed Sanders			36°/sec			FLIR MTI radar		8°		vehicles @ 6 km
	Raphael	19" dia	1.3 kg			20 µrad	CCD TV	visible			
Pan/Tilt Head	ESSI Robosoft	8" dia 16" hi	10 kg	360°/sec	RS-232	No					
Biclops	TRAC Labs		1.1 kg	120°/sec							

Table 5. Gimbaled sensor approaches

										
Company	TI	Nytech	TIFLIR-49	Hughes	Aselsan	WESCAM	FSI	Tamam	Controp	Inframetrics
Gimbal	CITV	G-210	WRA-1	HNVS	ASEL FLIR-200	Model 12	Ultra 6000	Outrider	DSP-1	IRTV-4456
Gimbal Dia	21.5 in	10 in	12.8 in	12 in	12 in	12 in	11 in	10 in	12.6 in	9.0 in
Gimbal Ht.	15 in	14.2 in	14.7 in	14 in	13 in	14.6 in	15 in	15 in		
Gimbal Wt.		25 lb	57 lb	42 lb		51 lb	42 lb	35 lb	57 lb	28 lb
Slew Rate	60°/s	200°/s	170°/s	170°/s		90°/s		60°/s		
Control I/F	RS-422	RS-422	1553B	1553B	1553B	RS-422				
Stabilization	Gyro	150 μr			Yes	35 μr	4-axis	60 μr	Yes	2-axis
Sensors	2nd gen FLIR	μbolom	2nd gen FLIR	2nd gen FLIR	2nd gen FLIR	InSb CCD	InSb CCD		InSb CCD	HgCdTe CCD
Wavelength	8-12 μm	8-12 μm	8-12 μm	8-12 μm	8-12 μm	3-5 μm	3-5 μm		3-5 μm	8-12 mm
FOV	13.3°x7.5°	40°x30°	30°x22.5°	40°x30°	3 FOV's	25°x25°	20°x20°			19°x14°
Pixels	1316x480	320x240								
Comments	Abrams	HTVS				Pioneer UAV		Outrider UAV		

The complete sensor approach for the STTV program, based on the trade studies conducted above, is shown in Figure 13. A panoramic sensor unit provides a low latency view of the vehicle's surroundings to give an idea of the nearby terrain and the locations of larger objects for good situation awareness. A gimbaled sensor unit provides high resolution detail sufficient to detect smaller objects such as a crouching enemy troop at 400 yards. The commander sees on his helmet-mounted display a 26°x19° segment of the panoramic image along with a higher resolution 15.5°x11.6° image from the gimbaled sensor. By moving his head he is able to pan and tilt the 26°x19° segment of the panoramic image with near-zero latency, keeping the 15.5°x11.6° image insert in the center of the field of view. The 26°x19° segment of the panoramic image uses CCD sensors with sensitivity in the visible region of the spectrum. The 15.5°x11.6° image from the gimbaled sensor uses a microbolometer sensor and is sensitive in the 8-12 μm region of the spectrum. Together, the two sensors provide a fused representation of the 15.5°x11.6° field of view that enables improved detection over either approach separately.

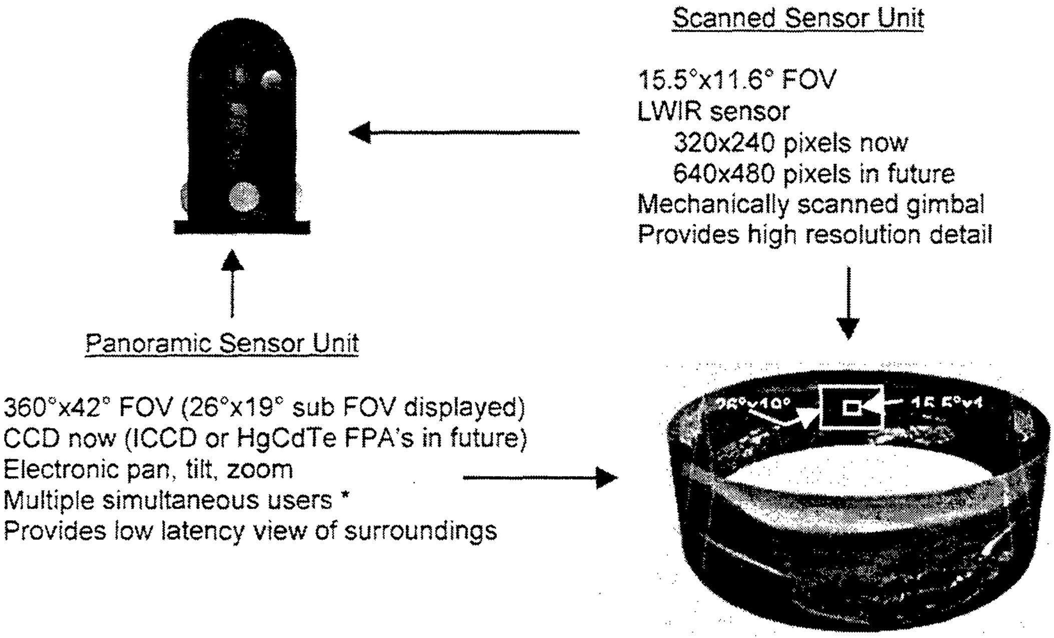


Figure 13. Complete STTV sensor approach

There are several advantages to this hybrid sensor approach. One advantage is that the gimbaled sensor can be replaced by a second generation FLIR sensor if the vehicle already has this superior sensor. This lowers the insertion cost of the STTV system while providing all of the advantages of increased situation awareness that the full STTV system provides. Another advantage is that a second user on the vehicle can view the data from the panoramic sensor on a separate helmet mounted display from the vehicle commander while allowing both users to pan and tilt within the panoramic image independently. This allows the squad leader in the back of an infantry fighting vehicle, such as a Bradley, to survey the area surrounding the vehicle prior to exiting, and to do this independently of the vehicle commander, who is more concerned with finding objects that affect the vehicle safety. A third advantage is that as Intensified CCD (ICCD) cameras and HgCdTe focal planes improve in resolution and lower in cost, the

panoramic sensor can be improved with these better sensors. The ultimate improvement is to have a panoramic sensor composed of HgCtTe focal planes that has a resolution equal to or better than the current second generation FLIR unit. In this case, one can dispense with the second generation FLIR unit on a vehicle and use only the HgCdTe panoramic sensor unit for both targeting and situation awareness. This is an attractive option for vehicles such as the FSCS and FCS currently in development.

3.3.4 Sensor Resolution Versus Wavelength Trade Study

Figure 14 shows the detector resolution of the resulting hybrid sensor approach versus the STTV system requirements. The data supporting this figure are included in Table 6. Figure 13 shows that none of the current panoramic camera approaches, including the mirrored PVSI approach using eight 640x480 pixel CCD cameras, currently meets the user requirement of detecting a human target at 400 yards. The PVSI approach does meet the need for a wide field of view situation awareness sensor at low latency. By adding a gimbaled sensor to the panoramic sensor one can improve the resolution of the combined sensors so that the combination can meet both the resolution requirement and the wavelength requirement. Figure 14 shows that a 320x240 pixel microbolometer sensor with a 26°x19° field of view is insufficient for this purpose. Merely improving its resolution to 640x480 pixels while keeping the field of view the same does not improve it enough to meet the requirement. However, a 320x240 pixel microbolometer sensor with 15.5°x11.6° FOV optics will meet the detection requirement, and an improved 640x480 pixel microbolometer sensor will almost allow one to recognize a human target at the same distance (not a requirement at this time). The penalty is a smaller field of view, which is regained by adding the panoramic camera portion of the hybrid sensor approach. Figure 14 shows that both the first and second generation FLIRs can meet the detection requirement and also recognize the object as a human target. However, their field of view is only 10°x7° or even smaller, so they also must be augmented by a panoramic camera approach to meet the need for improved situation awareness. Therefore, they can be used in place of the microbolometer sensor in the proposed hybrid approach but not in place of the panoramic camera component.

It is interesting to note that a division of the Boeing Corporation (formerly Rockwell Inc) is currently developing HgCdTe staring focal planes with partial support from ONR and has identified the objective of creating a panoramic sensor using this technology. By using eight 2048x2048 pixel focal planes in a panoramic camera, one can obtain a resolution nearly as good as the current first generation FLIR, and sufficient for both human object detection and recognition. Since this sensor will have a full 360° field of view, one would need only this panoramic camera to meet the current STTV requirements. Honeywell's proposed hybrid sensor approach provides an upgrade path which can incorporate this new technology development.

3.3.5 Monocular Versus Biocular HMD Trade Study

A trade study was performed to determine whether a monocular approach or a biocular approach would be the best HMD choice for the STTV system. Table 7 shows the advantages and disadvantages of a monocular approach versus a biocular approach. A binocular approach was included in the trade study for completeness. When considering the display of digital

information from an IVIS type of system, the field of view is unimportant, and the preferred approach is clearly a monocular approach with the advantages as shown in Table 7.

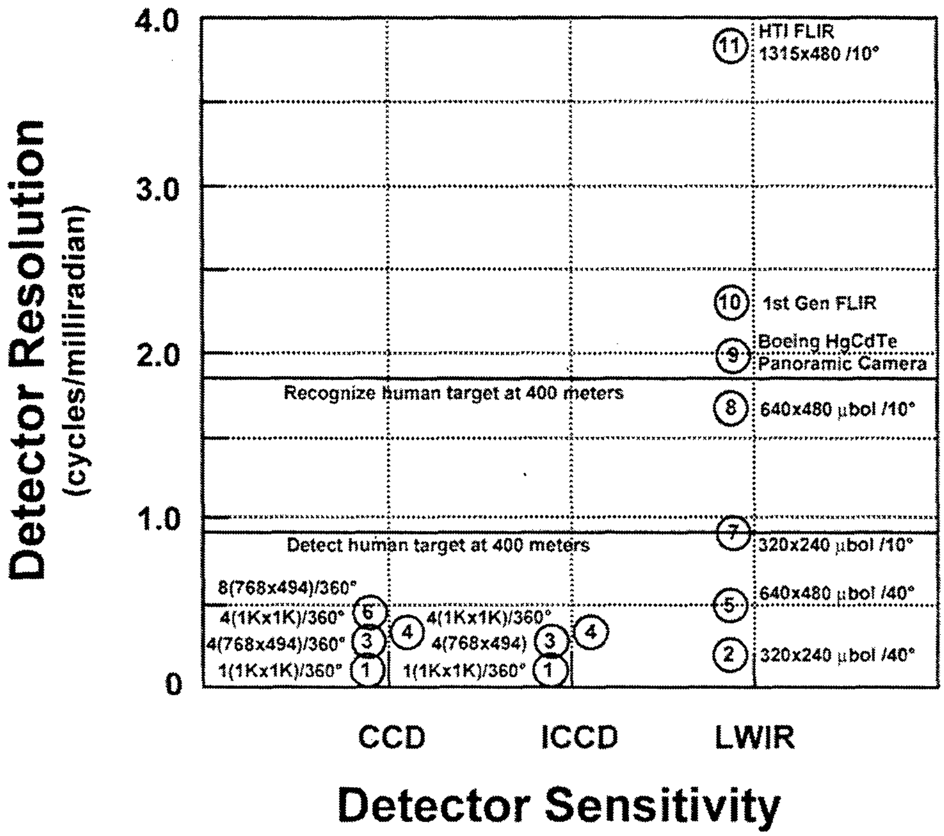


Figure 14. Detector resolution versus requirements

Table 6. Detector resolution versus requirements

No	Sensor	Pixels	FOV	Pixels per degree	Pixels per mr	Cycles per mr
1	Simple panoramic camera	1(1024x1024)	360°	2.8	0.16	0.08
2	DVE (current)	320x240	40°	8.0	0.45	0.23
3	4 fisheye lenses	4(768x494)	360°	8.5	0.49	0.25
4	4 fisheye lenses	4(1024x1024)	360°	11.4	0.65	0.32
5	DVE (future)	640x480	40°	16.0	0.90	0.45
6	I-sight camera	8(768x494)	360°	17.1	0.98	0.45
7	Microbolometer (current)	320x240	15°	21.0	1.21	0.60
8	Microbolometer (future)	640x480	15°	43.0	2.33	1.21
9	Boeing panoramic camera	4(640x480)*	360°		4.00	2.00
10	1st generation FLIR	~800 analog	10°	80.0	4.60	2.30
11	HTI 2nd generation FLIR	1316x480	10°	131.5	7.54	3.80
	Detection of human target (0.5mx1.5m) at 400 meters (1 cycle across target)					0.92
	Recognition of human target (0.5mx1.5m) at 400 meters (2 cycles across target)					1.85

* Split aperature optics used to diplex two azimuthal fields onto separate halves of each FPA

When considering the display of sensor information, the tradeoff is more complex because it is clearly advantageous to have the widest possible field of view for greater situation awareness. The field of view achievable by a partially overlapped biocular approach can be as great as 50° to 70° with 40° FOV optics for each eye, while the maximum field of view of a monocular approach is only about 40°. However, Honeywell's experience with the Apache IHADDS HMD display is that the additional 10° to 30° of field of view achievable is not worth the additional disadvantages shown in Table 7 for a biocular or binocular display. Therefore a monocular approach was selected for the STTV HMD display.

Table 7. Monocular versus biocular HMD approach

	Monocular	Biocular	Binocular
Advantages	Maintains dark adapted eye - Improves vehicle safety - Allows view of vehicle displays and outside environment Lowest head mounted weight Lowest cost - No critical alignment Lowest risk Highest reliability Operational product experience	Visual comfort Improved signal to noise Widest FOV potential with partial overlap Redundant image displays Lower training requirements	Stereo capability Visual comfort Improved signal to noise Moderately wide FOV potential Redundant images Lower training requirements
Disadvantages	Increased training requirements Visual discomfort, rivalry Non-symmetrical center of gravity Limited field of view	No dark adapted eye High head mounted weight Difficult alignment during construction More sensitive to optical aberations IPD-exit pupil adjustment issue Helmet stability critical Higher cost than monocular Less reliable than monocular	Complex sensor requirements No dark adapted eye High head mounted weight Difficult alignment during construction Most sensitive to optical aberations IPD-exit pupil adjustment issue Helmet stability critical Higher cost than monocular Less reliable than monocular

3.3.6 Color Versus Monochrome HMD Trade Study

A trade study was performed to determine whether a color HMD or a monochrome HMD would be the best choice for the STTV system. Table 8 shows the advantages and disadvantages of a color versus monochrome approach. When considering the display of monochrome sensor information, the preferred approach is clearly a monochrome HMD with the advantages as shown in Table 8 for a monochrome approach. When considering the display of digital IVIS type of information, a color display is preferred for reading the color map information. Considering that a combination of both applications is required, the preferred approach is clearly a color HMD approach. Therefore a color HMD approach is recommended for the STTV HMD display.

Table 8. Color versus monochrome HMD approach

	Color	Monochrome
Advantages	Simplifies map reading Enhances display of fused imagery Color coded symbology easier to interpret - Symbology overlayed on imagery - Friendly versus enemy forces - Emergency/critical conditions	Cheaper Less complex design Adequate for raw sensor imagery
Disadvantages	More expensive More complex	Obscuration or loss of map information Obscuration or loss of symbology information superimposed on sensor imagery

3.3.7 Direct View Versus See-Through HMD Trade Study

A trade study was performed to determine whether a direct view or a see-through HMD would be the best choice for the STTV system. Table 9 shows the advantages and disadvantages of a direct view versus see-through HMD approach. When considering the display of digital IVIS type of information, superposition of the IVIS information on the external world (external scene when outside the vehicle or tank interior when inside the vehicle) is not essential. Also, superposition of the two types of data is very sensitive to their relative brightness. When the two types of data are adjusted for equal clarity, the intelligibility of the IVIS data will be obscured by the see-through data. In this case the preferred approach is a direct view approach with the direct view advantages as shown in Table 9.

Table 9. Direct view versus see-through HMD approach

	Direct View Display	See-Through Display
Advantages	Cheapest Less detectible by enemy Look-over / look-under mode - provides view of environment (monocular mode only) - less sensitive to display versus environment brightness variations than see-through mode	Provides view of environment with a biocular display Can superimpose symbology onto view of environment
Disadvantages	No view of environment with biocular display	More expensive More easily detectible by enemy Causes confusion when different direct and displayed data superimposed More confusing when color symbology superimposed on color direct view Relative intensity of direct versus displayed data determines information seen or missed - Bright lights in direct imagery can wash out digital IVIS symbology - Bright digital IVIS symbology can wash out direct imagery

When considering the display of sensor information, the superposition of the sensor information with the see-through information can lead to further difficulties. When standing in the hatch, the vantage point of the sensor may not be the same as the vantage point of the commander's eyes, so the mis-registration of the two images may cause confusion. Also, when standing in the hatch the commander himself occludes the vision of the sensor in some directions, making the resulting superimposed images even more confusing in that direction. When inside the vehicle, the see-through imagery consists of the sensor information superimposed on the interior of the vehicle. Again, this superposition is very sensitive to the relative brightness of the two images and the intelligibility of the sensor data will be affected by the see-through data when the two images are adjusted for equal brightness.

In short, the use of an HMD to display IVIS symbology and sensor imagery in an armored vehicle differs from the use of an HMD in a helicopter application. In a helicopter application flight symbology and fire control symbology are superimposed on the external world, or on a FLIR image of the external world. This symbology is much simpler than the alphanumeric and map-type symbology of an IVIS type of display. It is also in a fixed position on the display or intentionally attached to an object in the external scene (e.g., a waypoint) rather than randomly associated with it as would be the case when viewing IVIS data superimposed on sensor data. This makes flight symbology and fire control symbology easier to understand. In an armored vehicle application there is no need to superimpose IVIS symbology on a view of the external world.

The armored vehicle situation with sensor data superimposed on a see-through view of the real world is more like the helicopter situation where the pilot must view FLIR imagery (as opposed to symbology) on an HMD display while seeing the external world or the instrument panel in the see-through mode. When seeing the FLIR imagery superimposed on the external world, the mis-registration of the two images due to the offset of the sensor from the pilot's eyes is known to be confusing. This mis-registration is tolerable only because the distance to the target is much larger than the sensor-to-eye separation distance. This mis-registration will be much worse for the ground vehicle application, where the distance to the target is shorter. In the case where the sensor imagery is superimposed on the instrument panel, the helicopter instrument panel displays are dimmed to avoid seeing them in the see-through mode. This reduces operator confusion.

Considering that it is not essential to superimpose IVIS symbology on the external world in the vehicular application, the preferred HMD approach is a direct view display. A direct view display allows the user to choose which data he wishes to see merely by looking at the display or by looking over, under, or around the display. Differences in brightness between the external world and the display content are not nearly as critical in the direct view case as when the two are superimposed. A direct view display can also be made less detectible by the enemy. For these reasons, a direct view display is preferred for the STTV system.

3.3.8 HMD Display Mounting Configuration Trade Study

Table 11 shows several potential approaches for mounting the display on the helmet. Approaches which mount the display on the helmet brow or on a frame worn over the helmet are not compatible with stowing sand, wind, and dust (SWD) goggles on the helmet, or with viewing

sensor ports with padded headrests inside the vehicle. They also add protuberances to the helmet that can make it difficult for a commander to pass through a hatch quickly. An eyeglass mounting approach offers no on-helmet stow position and is not easily stowed when inside the vehicle. An integrated goggle approach likewise offers no on-helmet stow position and is not easily stowed when inside the vehicle. It is also incompatible with viewing sensor ports with padded headrests, such as the GPS optic, inside the vehicle. A mounting approach which uses a stowable arm attached to the helmet is compatible with all these requirements. For these reasons, a stowable arm mounting approach is preferred for the helmet-mounted display.

3.3.9 Land Warrior HMD Compatibility Trade Study

It is desirable for the Army to have an STTV HMD that is compatible with the Army's dismounted Land Warrior day display (Figure 15). Benefits include interoperability, improved design for reliability, and lower life cycle cost due to the sharing of logistics services. There are several ways that an STTV HMD can be made compatible with the Land Warrior day display. These are shown in Table 10.

Figure 15. Honeywell Land Warrior day display

Table 10. Land Warrior compatibility options

Option	Drive Elect-ronics	Control Panel	Helmet Cable	Flat Panel	Optics	Helmet Mount	Compatible with				
							CVC helmet	640x480 IVIS	1st gen CITV	800x600 FBCB2	2nd gen CITV
1	LW	LW	LW	LW	LW	LW	No	Yes	No	No	No
2	LW	LW	LW	LW	LW	New	Yes	Yes	No	No	No
3	New	New	LW	LW	LW	New	Yes	Yes	Yes	No	No
4	New	New	New	640 x 480 color	LW	New	Yes	Yes	Yes	No	No
5	New	New	New	800 x 600 color	LW	New	Yes	Yes	Yes	Yes	Yes 4:3 output
6	New	New	New	1280x1024 color	LW	New	Yes	Yes	Yes	Yes	Yes 16:9 output

Table 11. Display mounting configurations

Display Mounting Configuration	Stowable Arm	Integrated into Goggles	Attached to Helmet Brow	Frame Worn Over Helmet	In Eyeglases
Example					
Compatible with wearing SWD goggles	Yes	Yes	No	Yes	Yes
Compatible with stowing SWD goggles	Yes	No	No	No	Yes
Compatible with NBC hood	Yes	Yes	Yes	Yes	Yes
Compatible with padded sensor head rests	Yes	No	No	No	Yes
Easily stowed when inside vehicle	Yes	No	No	No	No
On-helmet display stow position available	Yes	No	No	Yes	No
Provides unencumbered access through hatch	Yes	Yes	No	No	Yes
Land Warrior compatible	Yes	No	No	No	No

Table 10 shows that the current Honeywell Land Warrior display (Option 1) is compatible only with the 640x480 pixel IVIS display found on the M1A2 tank. To make it compatible with the CVC helmet used on an armored vehicle requires changing the helmet mount (Option 2). To make it compatible with the first generation FLIR CITV used on the M1A2 tank requires the electronics to be compatible with the RS-330 standard, which requires a new electronics design and also a new control panel (Option 3). Adding a 640x480 color flat panel display with matching electronics and cables (Option 4) does nothing to increase the compatibility over a 640x480 design. To make the Honeywell Land Warrior display compatible with the new 800x600 pixel color FBCB2 Applique+ display requires a new 800x600 color flat panel display, which also requires new drive electronics, a new control panel, and a new helmet cable (Option 5). This will also make it compatible with the new second generation FLIR CITV if the 4:3 aspect ratio RS-170 output is used. A new 1280x1024 pixel color flat panel display with new drive electronics, a new control panel, and a new helmet cable (Option 6), will make it compatible with both the 800x600 pixel color FBCB2 Applique+ display and the new second generation FLIR CITV with 16:9 aspect ratio RS-170 output. Since nearly all armored vehicles of the future will have the FBCB2 Applique+ digital display, which is 800x600 color, and the HTI second generation FLIR sensor, which has 1316x480 pixels, Option 5 is the preferred approach for meeting the STTV requirements.

In January 2000 after this trade study was completed, the Land Warrior day display was changed to an 800x600 pixel color display with a 40° field of view (Option 5). Therefore, only a new helmet mount and control panel are required to make this new Land Warrior display compatible with STTV requirements.

3.3.10 Head Tracker Trade Study

A head tracker is required to select the field of view to be displayed in the STTV helmet-mounted display. During the Phase I effort a tradeoff study was performed to select the best head tracker for the STTV requirement. Candidate trackers included Honeywell's Advanced Metal Tolerant Tracker (AMTT) and the commercially available IS-300 tracker from InterSense Inc (Figure 16).

Figure 16. InterSense IS-300 head tracker

The InterSense IS-300 tracker consists of two sensing cubes connected via ten foot long cables to a signal processor. Each sensing cube contains three angular rate sensors (MEMS tuning fork gyros), three accelerometers, and three magnetometers. The signal processor integrates the

outputs of the accelerometers to get the position changes of each sensor cube along an axis in inertial space. Since the angular rate sensors drift over time, a correction is applied to the gyro outputs whenever they are at rest to compensate for the drift. The compensation is determined by the change in orientation of the magnetometers with respect to the earth's magnetic field. The processed output from one sensor, therefore, yields the change in orientation of the sensor relative to the earth's gravitational and magnetic fields. When used as a head tracker on a moving vehicle, one sensing cube is attached to the turret of the tank and the other to the tank commander's helmet. The difference in output between the two sensing cubes indicates the relative orientation of the commander's helmet with respect to the turret position.

The IS-300 sensor was first tested for accuracy in a uniform static magnetic field in the laboratory. It was found to be repeatable to ± 3 degrees. It was then tested in a moving vehicle. One sensor was held stationary to the vehicle (near the transmission dome) while the other sensor was moved back and forth by hand (at shoulder height) to simulate side-to-side head motion. The vehicle was driven in a 15 meter diameter circle. Data collection started at the beginning of vehicle motion and stopped when the vehicle had completed the circle. The results are shown in Figure 17. The results show that the hand-held sensor unit behaved about as expected, with an oscillatory motion superimposed on a slower variation from 0° to 360°. Angles from 0° to 180° have a different sign than angles from 180° to 360° (i.e., -180° to 0°). The vehicle-fixed sensor did not behave as expected. It should have followed a path similar to that of the hand-held unit, but without the oscillation. However, it only indicated a motion from 0° to 100° and back to 0° again. This is believed to be the result of gyro drift caused by a lack of re-calibration due to the fact that the vehicle sensor is continuously moving. The hand-held sensor, on the other hand, gets re-calibrated because it is momentarily at rest while its direction of oscillation is changing. When both sensors are tied together in the laboratory, they have similar outputs as they are rotated through 360° because they both get re-calibrated while they are stationary as each measurement is taken.

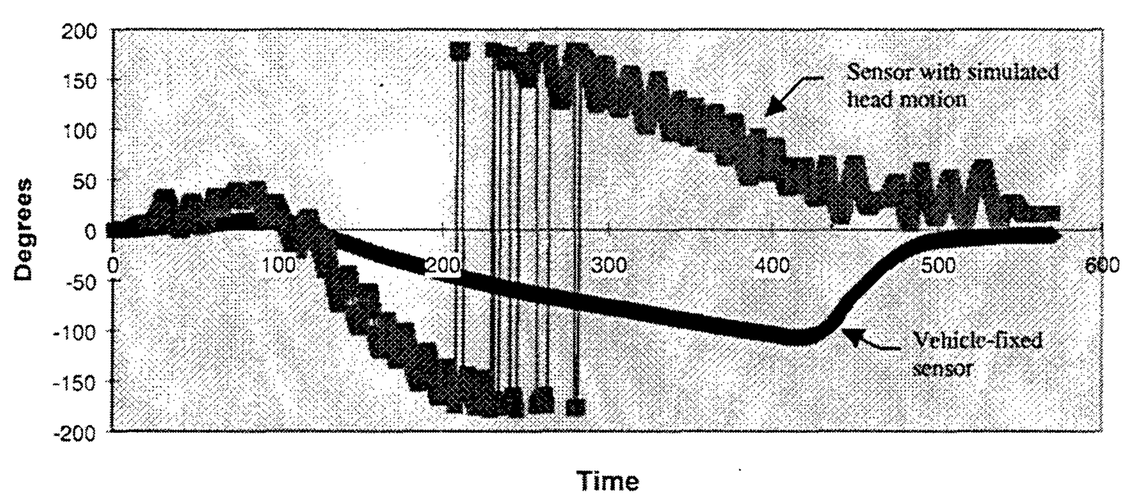


Figure 17. Evaluation results from IS-300 head tracker on a moving vehicle

These results lead to the conclusion that the InterSense tracker works adequately in a laboratory environment having stable and uniform magnetic fields, and when the required accuracy is no

better than a few degrees. However, it requires improvement before being used on a moving vehicle or on a vehicle that produces significant magnetic distortion.

The Honeywell AMTT tracker was tested on an M113 armored vehicle at the Minneapolis National Guard armory on 28 January 99 (Figure 18). The AMTT transmitter was installed inside the M113 passenger compartment approximately six inches below the roof, ten inches to the right of the vehicle centerline, and 14 inches behind the center of the commander's hatch. The AMTT receiver was mounted on a computerized mapping fixture that was translated throughout the volume of the commander's head motion box. The turret hatch was closed during the test. The overall results over a large head motion box (22"x24"x10") were as shown in Table 12.

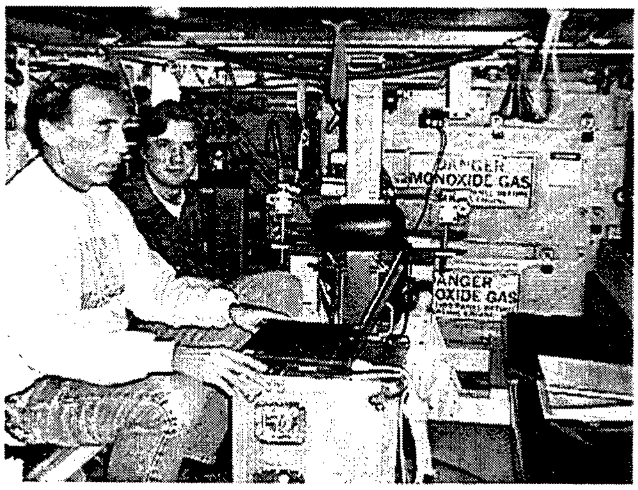


Figure 18. Testing the AMTT tracker on an M113

Table 12. Evaluation results for AMTT tracker on an M113

Angle Error in Degrees		Translation Error in Inches	
Azimuth	0.42	X (Fore/Aft)	0.04
Elevation	0.11	Y (Lateral)	0.07
Roll	0.36	Z (Vertical)	0.02

These results confirm that the AMTT tracker can be used for head tracking in armored tracked vehicles and is preferred over the InterSense tracker for accuracy purposes. However, the InterSense tracker is preferred for laboratory demonstrations because of its lower cost.

3.3.11 Demonstration Vehicle Trade Study

A trade study was performed to select an armored vehicle for the STTV system demonstration. Candidate vehicles were an Abrams M1A2 (Figure 19), a Bradley M2A2/A3 (Figure 20), and an M113 Armored Personnel Carrier (Figure 21). The Abrams M1A2 was preferred because of its perceived need for a helmet-mounted display and its prior use in other helmet-mounted display studies. However, M1A2's are available only from the U. S. Army Armor Center at Fort Knox, and are in heavy demand for training purposes due to their limited numbers. Therefore,

discussions with U. S. Army Armor Center representatives indicated that the likelihood of getting an M1A2 for two or three days for an STTV system demonstration would be nearly impossible. Similar discussions were held for the Bradley M2A2/A3, and similar conclusions were reached. Therefore, an M113 Armored Personnel Carrier was selected as the demonstration vehicle because it could be obtained from two sources: the Minnesota National Guard at New Brighton, MN, and the U.S. Army's Night Vision and Electronic Sensors Directorate (NVESD) at Picatinny Arsenal, NJ.

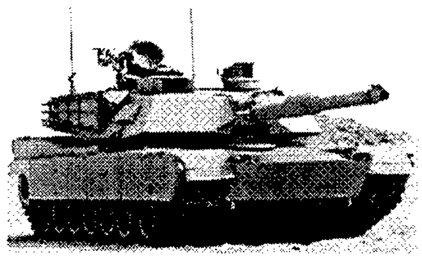


Figure 19. Abrams M1A2

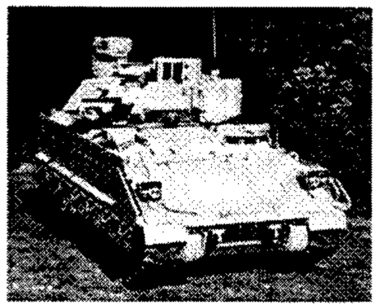


Figure 20. Bradley M2A3

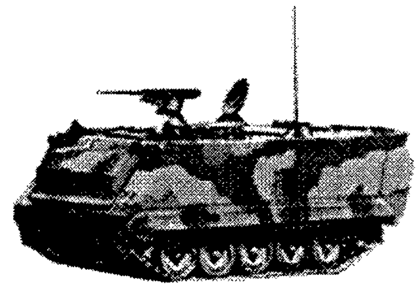


Figure 21. Gavin M113

3.3.12 Vehicle Interface Trade Study

STTV sensor location on the M1A2 tank. A trade study was performed to determine the optimum location for the STTV sensor on an M1A2 tank. Since the M1A2 tank already has a first generation FLIR CITV sensor (soon to be upgraded to an HTI second generation FLIR sensor), only the panoramic camera portion of the hybrid STTV sensor needs to be located. All of these locations must lie on the tank's turret or else it is necessary to pass the video signals through the tank's slip rings. This would require a major redesign of the slip ring assembly.

Figure 22 shows the three panoramic sensor locations considered. The locations are: 1) on the commander's hatch cover, 2) over the CITV sensor, and 3) on the turret bustle. Locating it on the commander's hatch cover (option 1) provides the best vantage point with the least occlusion and the least offset from the commander's normal viewing point, but raises obvious safety issues with the additional force required to open the hatch. Locating it on the turret bustle (option 3) provides a more protected mounting point with non-occluded viewing positions. Locating it over the CITV sensor (option 2) has the advantage of keeping the same origin for the panoramic camera and the CITV sensor, and provides a good vantage point with minimal occlusion. The CITV sensor, likewise, is not occluded by the STTV sensor or its mount because the STTV sensor can be mounted on the existing cover plate that protects the CITV sensor in its stow position. Therefore, the preferred sensor location on the M1A2 tank is over the CITV sensor as shown in option 2.

STTV controls location on the M1A2 tank. It is essential to have the STTV HMD controls accessible to the commander while he is standing in the hatch. Discussions with Army users emphasized that placing the controls anywhere on the commander's clothing was unacceptable due to the cumbersome nature of the items already being worn by the commander (fire retardent suit, outer garment, NBC mask with connections, intercom with connections, etc.). Figure 23 shows the possible control panel locations considered. One position was outside the hatch but

inside the vision blocks in a protected enclosure (Figure 23 (e)). Another position was inside the hatch underneath the vision blocks but over the Commander's Integrated Display (Figure 23 (f)). The latter position provides excellent accessibility to the commander in all positions of the hatch cover (Figure 23 (a) through (e)), as well as with the hatch totally closed. Therefore, the preferred control panel location is the one shown in Figure 23 (f).

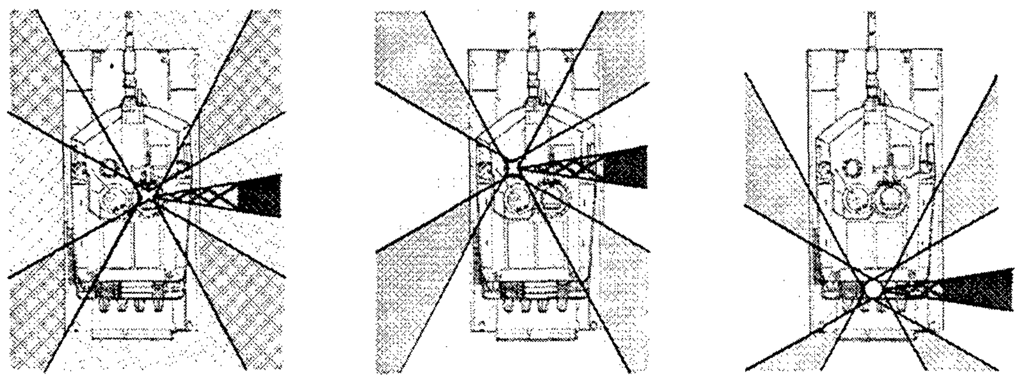


Figure 22. Panoramic sensor candidate locations on an M1A2 tank

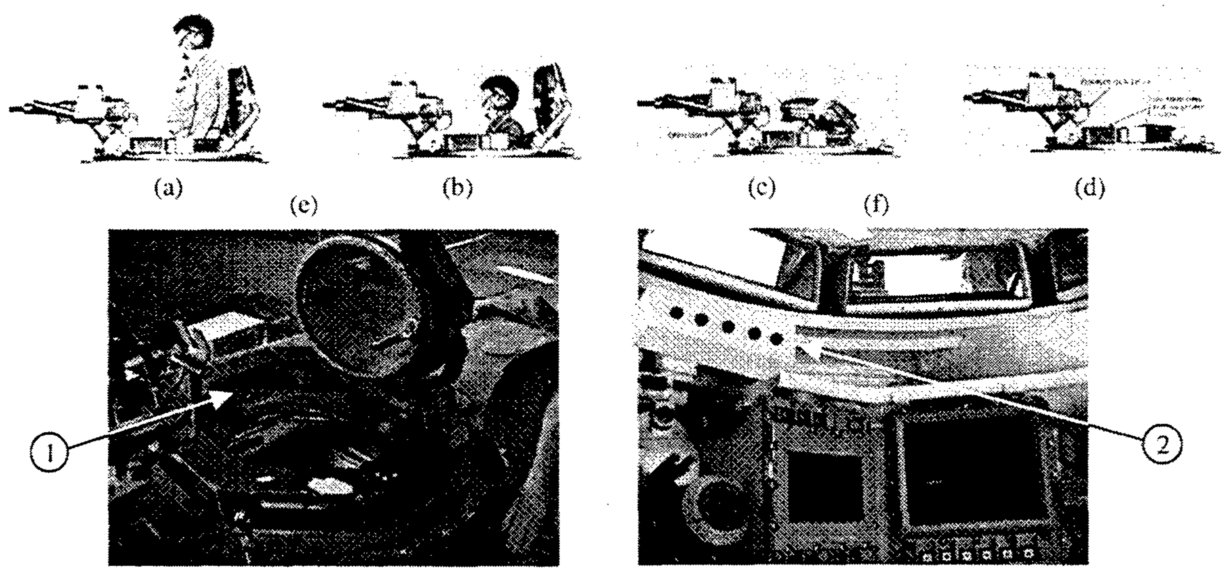


Figure 23. Candidate control panel locations on an M1A2 tank

<u>Sensor location on the M113 Armored Personnel Carrier (APC).</u> A trade study was performed to determine the optimum location for the STTV sensor on the M113 APC. One location considered was on top of the vehicle over the cover plate to the right and rear of the commander's turret (Figure 24 (c) (1)). This would allow bringing the cables into the interior through an existing hole in the vehicle. Also, the existing bolt holes currently used by the cover plate could be used to mount the sensor to the vehicle. However, this position would result in an offset in the sensor's vantage point from the commander's seated head position, which can cause problems in the use of the sensor. Another location considered was on top of the rectangular

ventilation hatch centered in back of the commander's hatch (Figure 24 (b) (2)) and Figure 24 (c) (2)). This location causes no offset in vantage point for the commander and is easily adapted to sensor mounting. Considering that the M113 is being used solely as a demonstration vehicle, the simplest sensor mounting scheme is to lock the rectangular hatch in its fully open position and to position the STTV sensor on a custom mounting platform that fits into the hatch opening. This automatically provides a means of bringing the cables into the vehicle, and allows rapid setup for demonstration. No modification of the vehicle is required.

(a) (b) (c)

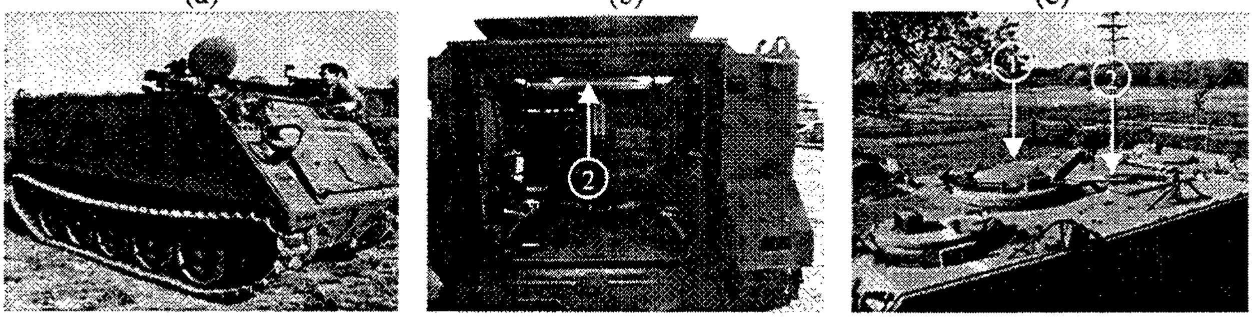


Figure 24. Candidate sensor locations on an M113

3.4 Prototype System Development Specification

A prototype system development specification was written that describes how the components selected in the trade studies can be integrated into a coherent system capable of meeting the established requirements. This specification is included in Appendix 2 of this report. The specification defines the system shown in Figure 25. It consists of a panoramic sensor unit containing both a staring sensor and a gimbaled sensor; an image processor; a helmet-mounted display with display control module; a helmet with display mount; a commander's control panel; a head tracker; a developer's control panel with joystick, an RS-232 switch, and a power supply. The vehicle commander can view on his helmet-mounted display either the panoramic sensor data or the FBCB2 situation awareness data. Panning of the sensor field of view is done automatically by the head tracker in response to the commander's head motion.

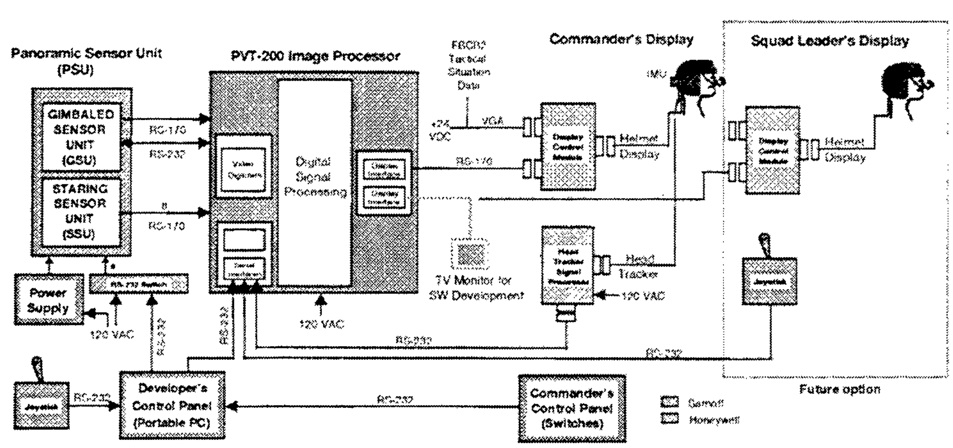


Figure 25. Prototype system block diagram

The commander can control the display brightness, contrast, and data selection via controls attached to his uniform, making it convenient to access these controls while he is either inside the vehicle or standing in the hatch. Sensor controls for display polarity, zoom, tracking reticle, and head tracker calibration are located on the commander's control panel that can be placed just inside the hatch, making it convenient to access these controls while inside the vehicle. Provision is made for an optional squad leader's display with joystick to allow a squad leader in the vehicle's passenger compartment to see the FBCB2 situation awareness data or to pan the sensor imagery directly before exiting the vehicle.

Performance capabilities of the prototype system are shown in Figure 26. These capabilities do not completely satisfy the system requirements shown in Figure 10 because program funding available in the program for system development was insufficient for developing entirely new performance-critical components such as panoramic infrared sensors and color helmet-mounted displays. Therefore, system development was limited to the use of commercially available sensors and the existing monochrome Land Warrior display. Similarly, the program funding was insufficient to perform vehicle integration tasks necessary to demonstrate the system on a moving armored vehicle. However, the prototype system defined in the development specification is capable of demonstrating the essential features of the required situation awareness visualization system in a laboratory or on a stationary armored vehicle. With minimal additional funding the system can be improved and integrated into a moving armored vehicle. Later, if field testing confirms the effectiveness of the prototype system concept, then further improvements can be made in sensor design, display design, tracker selection, and vehicle integration.

Sensor Performance

- 360° field of regard
- 26°x19° FOV
- in focus ≥15 feet
- 0.55 μm wavelength
- daytime operation only
- ≥150°/sec slew rate

Display Performance

- monocular
- non see-through
- 640x480 pixels
- 26°x19° FOV
- monochrome

System Performance

- able to detect human at 400 yards
- <66 msec sytem latency
- slew to cue capability

Figure 26. Prototype system capabilities

3.5 Prototype System Description

The following subsections describe the prototype system developed during the program.

3.5.1. 360° Panoramic Sensor

The 360° panoramic sensor (Figure 27) consists of eight 659x494 pixel visible charge-coupled device (CCD) cameras with each camera having a 6 mm auto iris lens with a field of view of 56°(H)x42°(V). The cameras point upward into eight planar mirrors tilted outward to provide a horizontal field of view of 360° and a vertical field of view of 42°. The vertical field of view is tilted downward 7° from the horizontal to place 2/3 of the vertical field of view below the horizon. The mirror arrangement allows the camera-to-mirror distance to be adjusted so that the cameras can be brought to a common virtual focal point, eliminating any parallax between the cameras. This assures that any objects in between two cameras are not doubly imaged or omitted, which can occur if camera vergence is not changed with distance as it is with human eyes. Actually, the camera-to-mirror distance is adjusted so that adjacent cameras have slightly overlapping horizontal fields of view to simplify the blending at image borders. This leaves a residual parallax due to a virtual camera separation of about ¼ to ½ inch, which is imperceptible at ranges beyond about 15 feet. A processor is then used to blend adjacent images into a combined intermediate camera view, enabling continuous panning through 360° as though one is looking at a single 360° panoramic image.

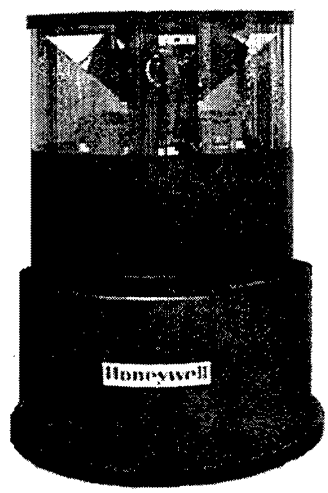


Figure 27. STTV panoramic image sensor

Another important sensor feature is that motion blur caused by image offset between two fields of the same frame is completely eliminated by selecting CCD cameras that have all the pixels in both fields illuminated within the same 1/60 second integration time. The two fields are then read out simultaneously into digital scan converters[12] that provide a standard field sequential RS-170 output. Additionally, the cameras have automatic gain control circuits and auto iris lenses that enable operation over a range of ambient illumination from 0.8 lux to 3×10^6 lux at f/1.4 (moonlit night to bright sunlight). The cameras also have an RS-232 interface that allows the processor to change the camera integration time and gain settings in real time.

The complete panoramic sensor is 14 inches in diameter by 23 inches high, which allows it to be placed on top of an armored vehicle and still see the ground 15 feet away. Alternatively, only the 13 inch high camera portion can be located outside the vehicle with the 10 inch high

electronics portion placed inside. The sensor has a transparent acrylic window to keep out dust and moisture.

3.5.2. Gimbaled Infrared Sensor

The gimbaled infrared (IR) sensor (Figure 28) is a commercially available unit developed by Nytech Inc. for the United States Army. It consists of a 320x240 pixel 8-12 μm microbolometer sensor with a 75 mm focal length lens that provides a field of view of 15.5°(H)x11.5°(V). The sensor has an RS-170 video output and an NETD of less than 0.100K. It is gimbal-mounted so that can be slewed in both the azimuth and elevation directions at rates approaching 200° per second and accelerations approaching 600°/sec^2. The azimuth gimbal is capable of continuous rotation. Its absolute pointing accuracy is one part in 4096, or 5 minutes of accuracy. The unit accepts position and velocity commands via an RS-232 interface and provides feedback of its intermediate gimbal positions while slewing. The complete unit is 14 inches high and 10 inches in diameter. It dissipates 20 watts at idle and up to 200 watts at maximum acceleration. In the STTV system this sensor is used to simulate the commander's forward-looking infrared (FLIR) sensor found on many armored vehicles, such as the CITV on the M1A2 Abrams or the Commander's Independent Viewer (CIV) on the M2A3 Bradley. If the vehicle already has a commander's FLIR onboard, this sensor can be omitted. Otherwise, it provides a low cost alternative to a high performance FLIR sensor.

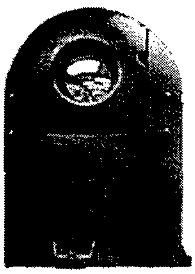


Figure 28. STTV gimbaled infrared sensor

The gimbaled infrared sensor can be mounted atop the 360° panoramic sensor to provide a merged sensor (Figure 29). The sensors can be used either singly or together in a fused mode as shown in Figure 30. When viewed on a helmet-mounted display, only a portion of the 360° field of view is displayed at one time. This portion is adjusted to be equal to the angular sub-tense of the display in front of the eye in order to make the scale factor of the displayed image equal to that of the real world. This makes the panning rate of the imagery in the display equal to the rate of head motion, which minimizes user discomfort. An electronic zoom capability is also provided.

3.5.3. Helmet-Mounted Display with Head Tracker

The prototype STTV helmet-mounted display (Figure 31) is a 640x480 pixel monochrome Active Matrix Electro Luminescent (AMEL) display with a field of view of 26°(H)x19°(V). It is mounted on a standard Combat Vehicle Crew (CVC) helmet in a way that allows convenient

viewing while minimizing interference when moving through the hatch or using an optical sight. The display mount has

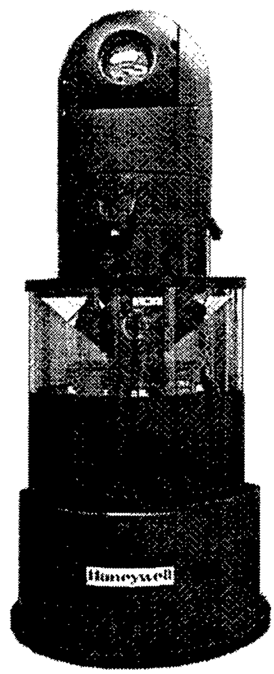


Figure 29. Combined panoramic and gimbaled IR sensors

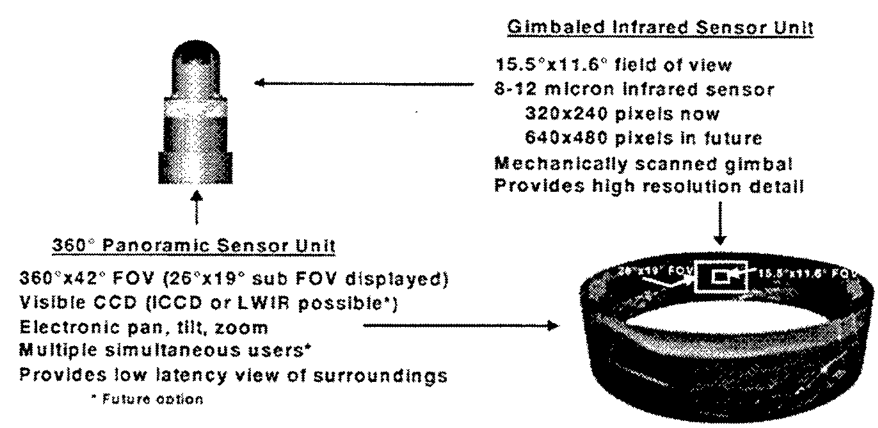


Figure 30. Operation and display of the combined STTV sensors

four detent positions: 1) a viewing position directly in front of the eye, 2) a viewing position seven degrees below the line of sight that allows looking over the display, 3) a stow position

beside the user's chin, and 4) a stow position behind the user's right ear. The mount allows adjustment of the display-to-eye distance, the inter-pupillary distance, and the horizontal detent position. The display has brightness and contrast controls and can be switched to display either STTV video or FBCB2 situation data. The same helmet mount can accommodate an 800x600 color display that provides improved intelligibility of the FBCB2 data.

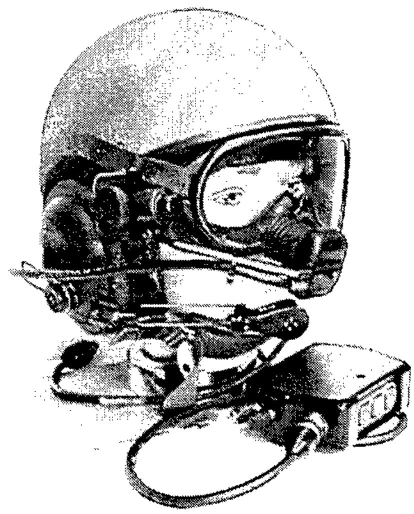


Figure 31. STTV helmet-mounted display

The prototype STTV head tracker is a commercially available IS-300 head tracker made by InterSense Inc (Figure 32). It has an angular accuracy of 1° to 3° RMS and an update rate of 150 Hz. Its 1.1x1.2x1.3 inch inertial measurement unit is attached atop the CVC helmet and provides three degrees of freedom via an RS-232 data link. The inertial measurement unit uses inexpensive angular rate gyros that provide acceptable performance in a laboratory environment. However, the update technique used to correct for gyro drift, based on sensing the earth's gravitational and magnetic fields during periods of head motion inactivity, is not intended for use on a moving armored vehicle. When operation on a moving armored vehicle is desired, Honeywell's metal-tolerant magnetic tracker can be used. This tracker has been tested on an M113 armored personnel carrier, and has been confirmed to operate with the accuracy needed by the STTV display system.

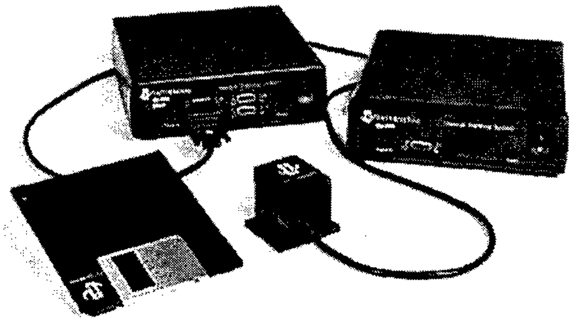


Figure 32. InterSense IS-300 head tracker

3.5.4. Image Processor

The STTV image processor (Figure 33) is a PVT-200 processor developed by the Sarnoff Corporation under previous DARPA contracts. It is sold commercially by Pyramid Vision Technologies. It consists of an 8-slot 6Ux160 subrack in a 14x19x11 inch enclosure. The eight slots are populated with a processor motherboard (two slots) and six video processor motherboards. The processor motherboard contains two C40 digital signal processors (DSP's) and two daughter boards, with each daughter board providing another C40 DSP. All four DSP's have 5 Mbytes of fast static Random Access Memory (RAM) each. Each video processor motherboard contains four 2 Mbyte and one 16 Mbyte simultaneous read/write frame store memories, four pyramid processors, and two reconfigurable processing elements, plus two video processor daughter boards. Each video processor daughter board performs a special-purpose video processing function such as warping, correlation, digitization of analog video, or displaying digital output in an analog format. The arrangement of video processor daughter boards is reconfigurable, and in the case of the STTV system consists of three digitizer boards for nine video channels, six warper boards for image transformations, one correlator board for three channels of image correlation, and two display boards. Video processing is accomplished by pipelining an image from a video frame store or DSP memory, routing it through one or more reconfigurable processing elements, daughter boards, or DSP's, and writing it back into a video frame store or DSP. Multiple video frames are processed simultaneously using high bandwidth programmable interconnections between the video memories and processing elements. Each motherboard has a crosspoint switch with a 1.2 Gbytes/sec bandwidth that routes its eight video input busses (33 Mbytes/sec each) to its various onboard processing elements and then routes their results to its eight video output busses. The motherboards, in turn, communicate with each other via a second crosspoint switch of 1.8 Gbytes/sec bandwidth that comprises the global backplane bus. This architecture allows multiple frames of video to be processed concurrently, yielding an equivalent processor throughput of 50 Giga-operations per second. The processor has nine RS-170 composite analog inputs, two RS-170 composite analog outputs, and four RS-232 control ports.

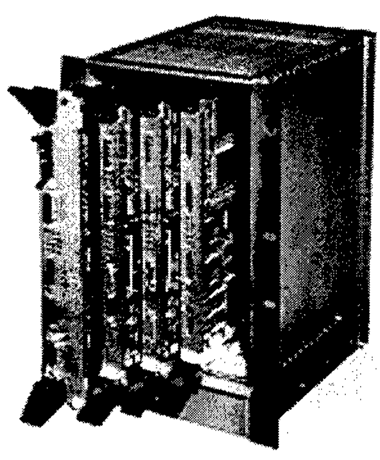


Figure 33. STTV image processor

The PVT-200 processor performs all of the image processing and control functions in the STTV system. It digitizes the outputs of the eight panoramic sensor cameras, selecting the one or two

video data streams that contain the commander's current field of view, and warping the images to correct for lens distortion. The processor then warps the adjacent images again in real time to synthesize two new sub-images in the correct line of sight direction, stitching them together and blending them to make a continuous image without any noticeable joints or seams. In the meantime, it slews the IR sensor to the same line of sight position and digitizes the IR camera output, displaying it either separately or fused with the visible sensor data. Electronic zoom is also applied. Finally, a moving object tracker is provided that enables the visible and IR sensors to remain locked onto a designated target while the vehicle and the user's head undergo arbitrary motion. Image stabilization can also be provided electronically via the PVT-200. The algorithms for these functions were adapted from algorithms developed by the Sarnoff Corporation under previous DARPA contracts.

3.5.5. Commander's Control Panel

The STTV system is controlled via the commander's control panel shown in Figure 34. The commander can choose to display the visible panoramic sensor only, the gimbaled IR sensor only, or both sensors together in a fused mode. A fourth selection enables the display of a second-generation FLIR sensor with appropriate warping of the imagery to show it on a display having square pixels. The IR imagery or FLIR imagery can be viewed as either white hot or black hot to allow for thermal inversion depending on the time of day. Viewing is done in response to the user's head orientation, which can pan through a full 360° of azimuth, 180° of azimuth, and 360° of head roll. By holding down the HMD VIEW toggle switch, the user can

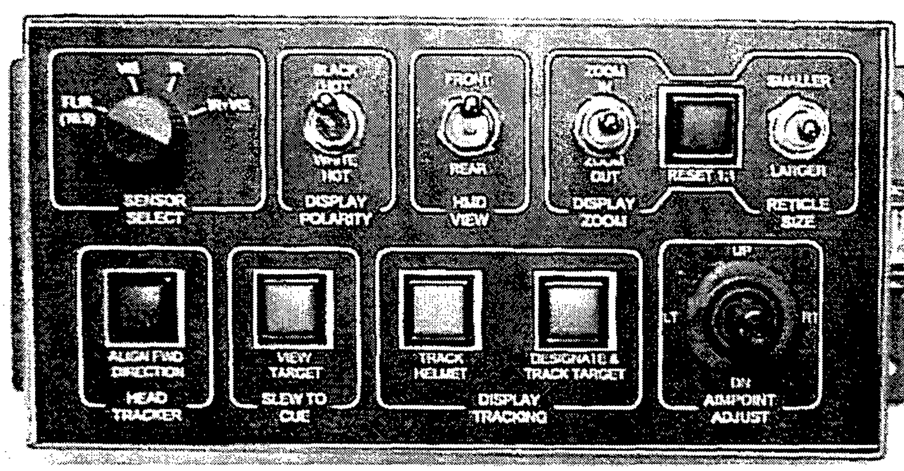


Figure 34. Commander's control panel

see a rear view 180° in back of his head while avoiding the need to turn his head 180°. When viewing imagery, the user can zoom either in or out or can make the size of the target reticle larger or smaller. These functions allow one to select an object in the current field of view, which can then be tracked by pressing the DESIGNATE & TRACK TARGET pushbutton. While the selected object is being tracked in a special tracking window by the visible and IR sensors, the user can continue to pan the visible panoramic sensor in an arbitrary direction in the original window. As the target object slides off the edge of the field of view, an indicator arrow appears to show the user in which direction he should turn his head to re-acquire the tracked object. The

user can view the target in the tracking window at any time by depressing the VIEW TARGET pushbutton. This function simulates the slew-to-cue function found on the M1A2 Abrams and the M2A3 Bradley. While pressing the VIEW TARGET pushbutton the user can re-center the tracking window on a smaller sub-object in the tracked object and then select that sub-object by using the DISPLAY ZOOM, RETICLE SIZE, and AIMPOINT ADJUST switches. Pressing the DESIGNATE & TRACK TARGET pushbutton a second time then causes only the smaller sub-object to be tracked. Releasing the VIEW TARGET pushbutton returns the display to the original window in the direction indicated by the user's head position, but with the target still being tracked in the unseen tracking window. When the user wishes to exit the target tracking mode he depresses the TRACK HELMET pushbutton, which returns control of the visible and IR sensors to the head tracker in the current head position. The remaining ALIGN FWD DIRECTION switch is used to align the head tracker to the forward-facing sensor direction, defined to be the front of the vehicle's turret. The user depresses this pushbutton while pointing his head forward in the turret as indicated by aligning a crosshair on the display with a mark on the turret's front wall. Alignment only needs to be performed once on system power-up. A complete description of the control panel functions is provided in Table 13.

3.5.6. System Block Diagram

A block diagram of the complete STTV system is shown in Figure 35. Figure 36 shows a photograph of the complete system.

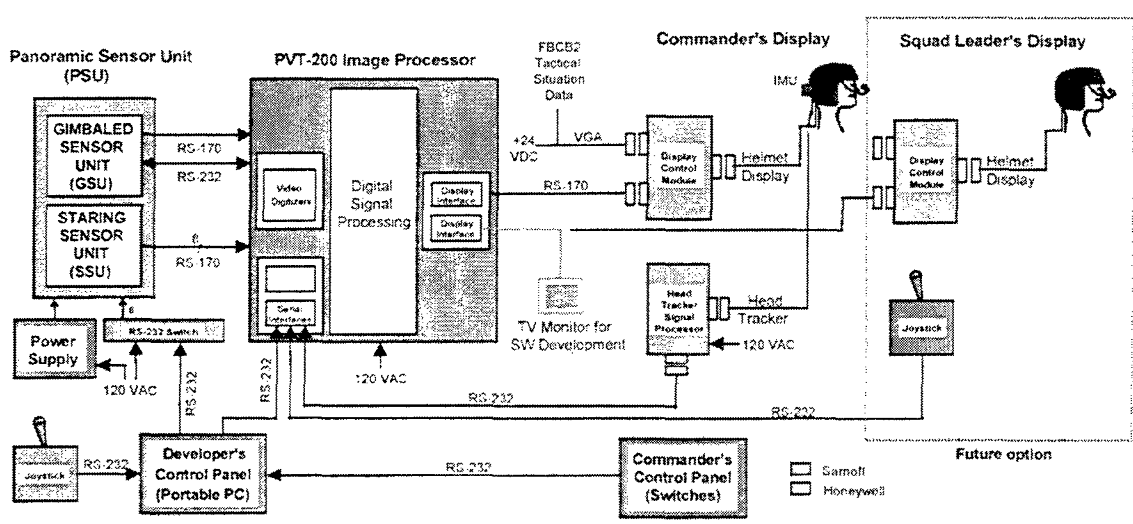


Figure 35. STTV system block diagram

The PVT-200 processor accepts imagery from the visible and IR sensors and generates RS-170 outputs for the vehicle commander's helmet-mounted display and an optional squad leader's helmet-mounted display. The commander controls both the visible and IR sensors via the commander's control panel and pans through the selected imagery using his on-helmet tracker. In a future option, the squad leader will have access to the imagery from the visible panoramic sensor, with a vehicle-mounted joystick for panning. The squad leader will then be able to pan and view the visible panoramic sensor in any direction independently of the vehicle commander while the vehicle commander is using the same sensor for other purposes. Both the vehicle

commander and the squad leader will have access to the FBCB2 tactical situation data on their helmet-mounted displays.

Table 13. Commander's control panel functions

		Description of Operation		
Function	Switch Type	Visible Sensor Only	IR Sensor Only	Visible & IR Sensor
Sensor Select • Visible sensor only • IR sensor only • Visible and IR sensors "fused" • 2nd gen FLIR	Rotary switch (with 4 detents)	26x19 FOV displayed across 640x480 pixels	15.5x11.6 FOV displayed in appropriate subset of display FOV	26x19 visible FOV displayed with15.5x11.6 IR FOV superimposed
Display Polarity Select • Black hot • White hot	Toggle switch (with 2 detents)	Inoperable	Inverts image bits of IR sensor only.	Inverts image bits of IR sensor only.
Zoom mode select • Continuous zoom in • Maintain zoom • Continuous zoom out • R[illegible] mode	Toggle switch (spring loaded in 2 directions with neutral in middle) + Push button (for 1:1 RESET)	Visible sensor only is zoomed. Zoom can be activated in all modes below, but only the head-tracked display will be zoomed, while the target-tracked view is not zoomed.	IR sensor only is zoomed. Zoom can be activated in all modes below, but only the head-tracked display will be zoomed, while the target-tracked view is not zoomed.	Zoom can be activated in all modes below, but only the head-tracked display will be zoomed, while the target-tracked view is not zoomed. If head-tracked display is viewing both sensors, then both sensors are zoomed together. Otherwise, only the sensor being displayed will be zoomed.
[illegible] • [illegible] • [illegible]	Toggle switch (spring loaded in 2 directions with neutral in middle) + common push button RESET with zoom mode)	For each bump of the toggle switch, the reticle is changed to a larger or smaller reticle size. Reset switch restores reticle to original one.	For each bump of the toggle switch, the reticle is changed to a larger or smaller reticle size. Reset switch restores reticle to original one.	For each bump of the toggle switch, the reticle is changed to a larger or smaller reticle size. Reset switch restores reticle to original one.
[illegible] • [illegible] • [illegible] [illegible] camera [illegible] to the [illegible]	Toggle switch (spring loaded in 1 direction so normally in direct view mode but changeable to rear view if hold switch in spring loaded direction) OR push button (with rear view down)	Visible sensor only, front view or rear view. Rear view is 180° from current head tracker position, and may be direct image or mirrored image (pre-determined by developer).	IR sensor only, front view or rear view. Rear view is 180° from current head tracker position, and may be direct image or mirrored image (pre-determined by developer).	Both IR and visible sensors, front view or rear view. Rear view is 180° from current head tracker position, and may be direct image or mirrored image (pre-determined by developer).
[illegible] • [illegible] • [illegible]	Two pushbuttons: 1) Designate/track target and 2) Track helmet	Commander designates target by pressing button when target is 5within reticle. Visible sensor continues to track target while commander can look for new targets in a second view of the same sensor (i.e., the second view slews in response to head motion). Coordinates of tracked target remain accessible to vehicle to enable turret to be slewed to target when desired. Target tracking feature is released and visible sensor is slewed by head tracker.	Commander designates target by pressing button when target is within reticle. IR sensor continues to track target. When commander looks away from target, the target slides off the display and the commander no longer sees the IR sensor. Coordinates of tracked target remain accessible to vehicle to enable turret to be slewed to target when desired. Target tracking feature is released and IR sensor is slewed by head tracker.	Commander designates target by pressing button when target is within reticle. IR sensor continues to track target. Commander can look for new targets in the visible sensor (i.e., the visible sensor slews in response to head motion). Coordinates of tracked target remain accessible to vehicle to enable turret to be slewed to target when desired. Target tracking feature is released and both visible and IR sensors are slewed by head tracker, with IR imagery superimposed or "fused" onto visible imagery.
[illegible] • [illegible] • [illegible] • [illegible] • [illegible]	4 position joystick-action digital microswitch	Moves reticle by a small amount in the selected direction across the tracked image while the tracked image remains fixed in the display while in the tracking mode.	Moves reticle by a small amount in the selected direction across the tracked image while the tracked image remains fixed in the display while in the tracking mode.	Moves reticle by a small amount in the selected direction across the tracked image while the tracked image remains fixed in the display while in the tracking mode.
[illegible] • [illegible] HMD [illegible] • R[illegible] tracking mode	Push button switch continuously held down (or spring loaded toggle switch held against spring) Push button switch not pushed (or spring loaded toggle switch not held against spring)	Imagery on commander's display is changed from head tracked mode to a view of the designated (tracked) target uncoupled from the head tracker. Return to target tracking mode described above, with target being tracked by the visible sensor in one view (undisplayed) and display showing another view of visible sensor slewed in response to head motion.	Imagery on commander's display is changed from head tracked mode to a view of the designated (tracked) target uncoupled from the head tracker. Return to target tracking mode described above, with target being tracked by the IR sensor in one view (undisplayed) and display slewed in response to head motion, showing blank data when not in the FOV of the sensor.	Imagery on commander's display is changed from head tracked mode to a view of the designated (tracked) target uncoupled from the head tracker. Return to target tracking mode described above, with target being tracked by the IR sensor in one view (undisplayed) and display showing the visible sensor slewed in response to head motion.
Head Tracker [illegible] • Set forward (head) direction	Pushbutton switch associates current head position with visible and IR sensor lines of sight facing to the front of the turret. Active in all sensor modes.			

Notes:

1) The reticle type, size, and shape can be easily changed by modifying a reticle file in the software.
2) The tracker will track whatever is inside a reticle box, whose size can be varied at the operator's command.
3) Rear view is defined to be the direct view (i.e., not inverted left-right) 180° in back of the commander's head current head position.
4) Sensor imagery is aligned to the head with three degrees of freedom; i.e., azimuth, elevation, and head tilt. The user can initialize the sensor line of sight to be coincident with his head azimuth and elevation at a time when the user is looking forward in the vehicle. The tilt degree of freedom cannot be initialized at this time.
5) The processor will warp 2nd generation FLIR imagery in real time so that 1.5:1 imagery can be displayed properly on a commercial 1:1 display. This function has not yet been tested.
6) The table should have another column entitled "2nd generation FLIR only". The only modes implemented in this column should be the display polarity and zoom select modes.

The prototype STTV system uses a laptop computer as a control panel for development purposes to facilitate system changes and to aid in software development. In a deployable STTV system the laptop computer will not be used and the commander's control panel will communicate directly with a ruggedized version of the PVT-200 processor.

Figure 36. Integrated STTV system

3.6 Deployable System Features

The prototype STTV system is useful for demonstrating system operation, but does not address all of the system requirements because it uses existing components to reduce development cost. A deployable STTV system will use improved components that are better matched to the system requirements. It will also have additional image processing functions and more complete integration into the vehicle systems. Table 14 shows some of the improvements envisioned in a deployable STTV system.

One major improvement is upgrading the 360° panoramic sensor from visible sensitivity to 8-12 micron sensitivity. One alternative for achieving this is by using a parabolic metal mirror and a single staring HgCdTe focal plane having 2048x2048 pixels. A prototype sensor of this type having a 640x480 pixel focal plane has already been developed. Alternatively, it may be possible to mosaic several 640x480 pixel microbolometer focal planes to achieve a similar result. Sensor resolution can be improved by the use of larger focal planes with more pixels and by micro-scanning techniques. A suitable IR-transparent cylindrical window will also be supplied. Protection against small arms fire can be provided in the form of a retractable armor cylinder that can be raised or lowered around the sensor or, alternatively, by elevating the sensor out of a protective well.

The gimbaled IR sensor can be improved by using a second generation FLIR having 1316x480 pixels and dual field of view optics. This sensor is already available on some armored vehicles,

and additional vehicles will be receiving it as an upgrade package. If an 8-12 micron 360° panoramic sensor is provided as described above, a second generation FLIR may not be needed if the range of the panoramic sensor exceeds the range of the vehicle's weaponry.

Table 14. Improvements envisioned in a deployable STTV system

Function	Prototype System	Deployable System
360° panoramic sensor	Visible sensitivity 8 cameras 5120 (H) x480 (V) pixels acrylic window unshielded	8-12 micron sensitivity 1 camera 8000(H)x500(V) pixels IR-transparent window retractable armor shield
Gimbaled IR sensor	320x240 microbolometer 15.5°(H)x11.5°(V) FOV optics	1316x480 2nd gen FLIR sensor dual narrow & wide FOV optics
HMD display	640x480 monochrome HMD 26°x19° FOV	800x600 color HMD wider FOV
Head tracker	commercial inertial tracker	metal-tolerant magnetic tracker
Image processor	8-slot PVT-200 processor	Next generation PVT processor
Image processing functions	image stitching electronic zoom visible/IR fusion moving target tracking	+ wider display FOV + image stabilization + 2nd viewer + UAV imagery – visible/IR fusion (not required)
Vehicle integration	non-integrated	Sensor integration with vehicle STTV control integration FBCB2 display integration 2nd gen FLIR integration Fire control system integration Embedded training Embedded maintenance

The helmet-mounted display can be improved by upgrading to an 800x600 pixel color flat panel display to increase resolution and to improve color contrast for FBCB2 map information. The higher resolution flat panel display will also have a wider field of view that will add more content to the sensor imagery. The head tracker will be a metal-tolerant magnetic tracker with electronics that fit onto a single card. The single card construction will aid significantly in reducing tracker cost. A prototype of this tracker has been proven effective on an M113 armored vehicle[23], and transition to manufacturing is currently in progress.

The deployed system will include additional image processing functions such as higher sensor resolution, wider display field of view, electronic image stabilization, provision for a second independent viewer of the 360° panoramic camera imagery, and provision for displaying Unmanned Aerial Vehicle (UAV) reconnaissance imagery. These additional functions will require higher processor throughput, which will be achieved by using a next generation PVT processor.

Most importantly, the deployed system will be integrated into the vehicle and its systems much more effectively than the prototype system. The STTV sensors will be mounted on the outside of the vehicle in a manner that protects them from abuse and in a location that increases their effectiveness without compromising other vehicle sensors or functions. The STTV controls will be mounted inside the vehicle in a location that is accessible to the commander while he is standing in the hatch or with the vehicle buttoned up. The controls will be integrated with the second generation FLIR sensor controls and the vehicle fire control system so that the hunter-killer teamwork between the vehicle commander and the gunner can be maintained. The STTV helmet-mounted display will be integrated with the FBCB2 tactical terminal and second generation FLIR so that FBCB2 information and second generation FLIR imagery can be displayed effectively and still be controlled properly by the originating systems. Finally, the STTV system will be integrated with new systems still in development for embedded training and embedded maintenance that offer the possibility of reducing vehicle life cycle cost.

3.7 Vehicle Applications

The STTV system is designed primarily for turreted armored vehicles, such as the M1 Abrams and the M2 Bradley (Figure 37). It is usually these vehicles that impose the heaviest demands on the vehicle commander's workload. However, non-turreted armored vehicles, such as the M113, are also potential insertion candidates. New armored vehicles currently in development, such as the Crusader, the Future Scout and Cavalry System (FSCS), the Future Combat System (FCS), and the new family of Medium Armored Vehicles are considered to be especially strong candidates for the STTV system. The FCS program has formally identified the need for a panoramic sensor. The U. S. Army Tank Automotive and Armaments Command (TACOM) has also investigated the use of a panoramic sensor with helmet-mounted display as a see-through turret system for this purpose.

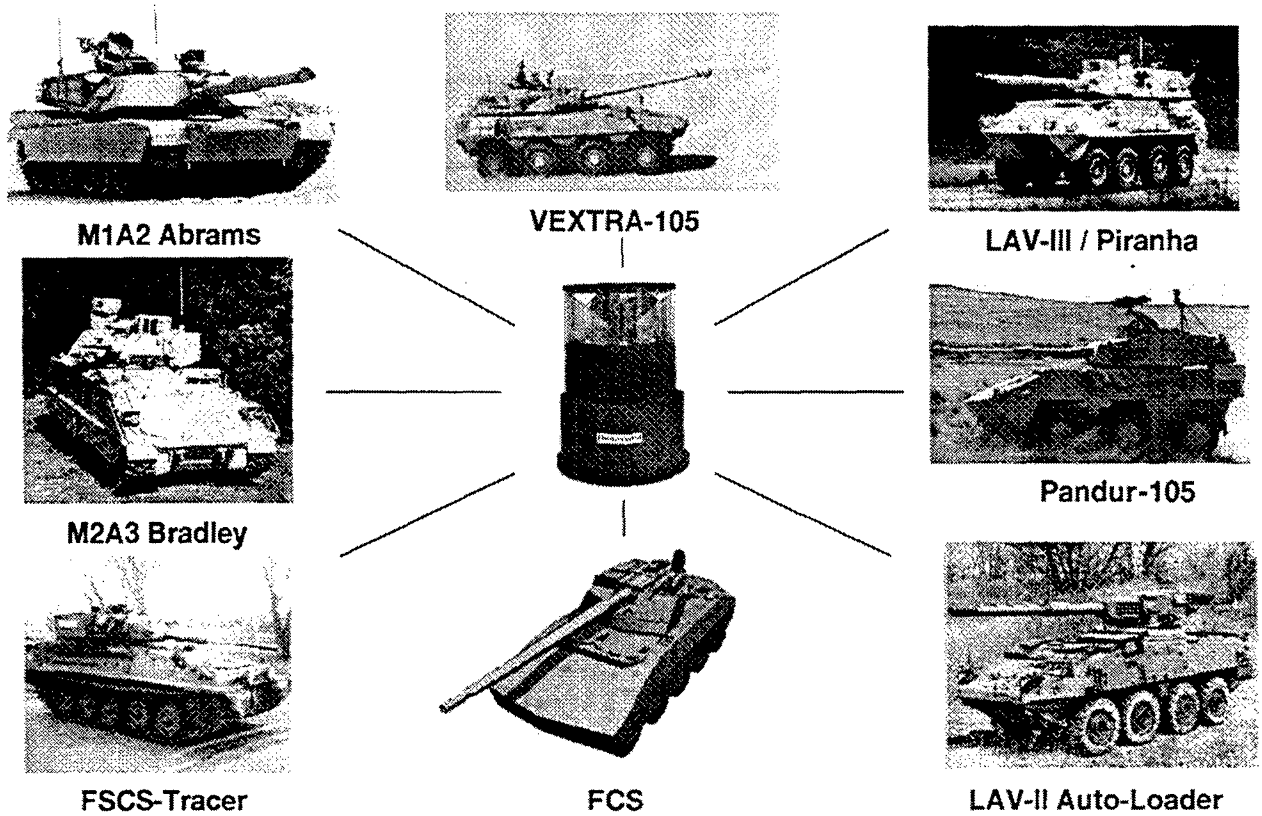


Figure 37. Vehicles identified for STTV insertion

3.8 System Evaluations and Demonstrations

The prototype STTV system was evaluated on a HMMWV vehicle at the Sarnoff Corporation on 3 May 00 (Figure 38). The STTV system included the visible and IR sensors, image processor, InterSense head tracker, commander's control panel, and power supply. Image processing software for warping, stitching, zooming, interpolating, and displaying both sensors was operational, along with head tracker and reticle operation. Software for target tracking and automatic camera-to-camera brightness adjustment was not yet operational. A surrogate head-mounted display (Sony Glasstron) was used in place of the Land Warrior display. The vehicle contained a 1 kW battery-fed 110 VAC inverter plus a gasoline-operated generator for recharging the battery.

Imagery from the visible and IR sensors was observed under varying conditions of ambient brightness, target contrast, target range, head motion, and vehicle motion. The IR imagery was clear and relatively noise-free once the IR sensor had gone through its internal calibration procedure. The visible imagery was noise-free, but did not have as good a resolution as the IR imagery. Nevertheless, it was easy to detect and track objects such as humans, automobiles, and wildlife at ranges of 100 to 400 meters. Stitching of the visible imagery from adjacent cameras was very smooth, but brightness variations from camera to camera made it possible to discern the camera stitching locations. It was difficult to adjust the brightness levels by hand so that all cameras had the same brightness level.

The InterSense head tracker worked well while the STTV system was powered from the battery with the generator off. The tracker operated acceptably even while the vehicle was moving, which might be ascribed to the lack of metal in the HMWWV vehicle (it had a canvas roof, for example). Latency was nearly unnoticeable for the gimbaled infrared (IR) sensor, but was much slower for the visible sensor. When the STTV system was operated with the generator on, the head tracker would drift continuously.

Approximately two hours worth of sensor imagery was recorded on digital tape using a Sony 450X digital camcorder. The digital imagery was edited into a two-minute long repeating VHS video tape that could be shown on a helmet half-shell display at the AUSA show later in the month.

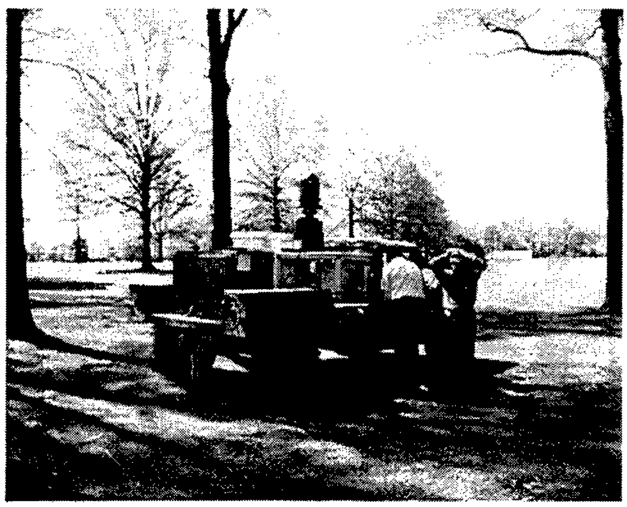


Figure 38. System evaluation at the Sarnoff Corporation on 2-4 May 00

The STTV system was demonstrated for the first time at the Fort Knox Armor Conference on 22 to 24 May 00 (Figure 39). The system configuration was identical to the one evaluated at the Sarnoff Corporation on 3 May 00, except that the imagery was displayed on a surrogate Land Warrior helmet-mounted display mounted on a half shell. The surrogate display was a 640x480 pixel monochrome display with the same optics and AMEL flat panel display as Land Warrior display, but with different controls and drive circuitry (Honeywell's marketing demonstration unit). The InterSense head tracker was located on the table under the half shell so that an observer could easily pan and tilt the imagery by hand. A CVC helmet with the STTV display and STTV display mount was exhibited separately on a mannequin. The visible and IR imagery was excellent, although the brightness adjustment from camera to camera was still done by hand. The exhibit attracted a lot of attention from active Army personnel. Many armor sergeants noted that something like this was needed on Abrams and Bradleys.

A second STTV demonstration was given at the AUSA Annual Meeting in Washington, DC, on 16-18 October 00 (Figure 40). The STTV system was part of a UDLP exhibit showing UDLP's all-electric vehicle. The STTV system configuration was identical to the one demonstrated at the Fort Knox Armor Conference on 22-24 May 00, except that a track ball was used for panning the

imagery versus using the InterSense head tracker. The image processor software was an improved version that incorporated an automatic brightness adjustment algorithm for setting the brightness levels of the eight cameras. The STTV system operated flawlessly, but the exhibit was not heavily attended because of its remote location outside the main exhibit hall.

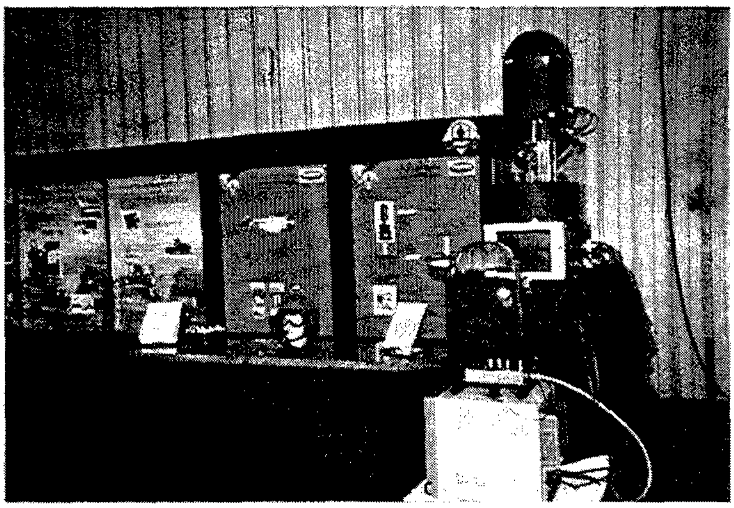


Figure 39. System demonstration at Fort Knox Armor Conference on 22-24 May 00

Figure 40. System demonstration at AUSA Annual Meeting on 16-18 October 00

Section 4.0 Conclusions

This report documents the results of contract DAAN02-98-C-4034, See-Through Turret Visualization Program. The program was sponsored by Dr. Norman Whitaker of DARPA/ITO under DARPA/ITO's Warfighter Visualization effort. It was managed by Mr. Henry Girolamo of the U. S. Army's Natick Soldier Systems Center. Honeywell Inc. was the prime contractor and the Sarnoff Corporation was the major subcontractor.

The program resulted in the following major accomplishments:

- surveyed Army users to understand the needs of an armored vehicle commander for situation awareness information,
- wrote a system requirements specification documenting the needs of an armored vehicle commander for situation awareness information,
- performed trade studies to identify the optimum solution for meeting the system requirements,
- created a prototype system development specification that defines a system architecture having a sensor, image processor, and helmet-mounted display capable of satisfying the vehicle commander's needs for situation awareness information,
- developed hardware and software for a prototype system capable of demonstrating the essential features of the visualization system on a non-moving armored vehicle. Specifically, the program developed:
    - a 360° FOV panoramic sensor having eight visible CCD cameras and capable of simultaneous readout by two different users,
    - a gimbaled IR sensor with uncooled IR focal plane and high speed pan/tilt capability,
    - IR image processor hardware and software capable of real time image warping, mosaicing, target tracking, sensor fusion, displaying, and controlling the operation of the visible and IR sensors,
    - a commander's control panel for controlling the panoramic and gimbaled IR sensors while the commander is standing in the hatch or buttoned up inside the vehicle,
    - a display mounting approach for mounting the Land Warrior display on a CVC helmet while retaining full use of sand, wind and dust goggles and the vehicle's optical sights and while avoiding problems with head clearance, cable snagging, and emergency egress,
- identified candidate armored vehicles that can benefit from using the STTV system,
- identified STTV sensor and control mounting locations on the candidate vehicles,
- identified an armored vehicle for hosting a final system demonstration,
- conducted demonstrations of the prototype system at the Fort Knox Armor Conference and the annual AUSA meeting,
- identified system improvements that can be included in a deployable STTV system,
- delivered a paper at the SPIE Conference describing the STTV system.

Lessons learned from the prototype STTV system were as follows:

- The mount for the Land Warrior display on the CVC helmet provides an effective solution for mounting the display on the CVC helmet.

- A helmet-mounted display with head tracker can display the vehicle's CITV/CIV sensor imagery when buttoned up. However, current armored vehicle sensors (e.g., the Abrams CITV or the Bradley CIV), pan very slowly (approximately 60°/sec) and thus introduce objectionable latency with normal head motion. Therefore, a specialized STTV sensor having a faster panning rate (approximately 120°/sec) is required for use with a head-mounted display and head tracker.
- The resolution of the visible panoramic sensor was less than that of the gimbaled IR sensor. The number of panoramic sensor pixels displayed was limited by the display field of view to be 26/56 x 640 = 297 pixels across the 26° horizontal field of view, or 11.4 pixels per degree. The number of IR sensor pixels displayed was 320 pixels across a 15.5° horizontal field of view, or 20.6 pixels per degree. This assumes that helmet-mounted display is designed so that the field of view of the displayed imagery is equal to the angular subtense of the display in front of the eye in order that the displayed imagery overlaps 1:1 with the real world (even if the display is not a see-through display). This condition is known to minimize motion sickness, which worsens when the displayed imagery moves at a different speed than the head motion (e.g., when the imagery is zoomed in or out).
- Panoramic sensor resolution can be improved by using CCD cameras having a larger number of pixels.
- The latency of panning the visible panoramic sensor with the head tracker was longer than the latency of panning the gimbaled IR sensor. This latency was due to processing delays in the image processor software.
- Fusion of the IR sensor imagery with the visible panoramic imagery was hampered by the parallax between the IR and visible imagery caused by the vertical offset of the camera focal points (approximately 16 inches).
- The tracking of a target as it passes from one visible sensor in the panoramic camera to another complicates the software tracking algorithms.
- The PVT-200 image processor throughput was fully utilized for the functions of image warping, mosaicing, displaying, and target tracking. The inclusion of additional image processing functions (such as a second viewer with independent panning capability) will require eliminating some existing function (such as target tracking), or the expansion of image processor throughput.
- The prototype STTV system is capable of being demonstrated on a non-moving armored vehicle.
- Operation of the prototype STTV system on a moving armored vehicle will require improvements in the head tracker (e.g., optical updating of the inertial sensor) or use of a metal-tolerant head tracker (e.g., Honeywell's AMTT head tracker).
- Funding limitations precluded full system evaluation with armored vehicle commanders.

As a result of the lessons learned from the prototype STTV system, the following conclusions can be drawn about a deployable STTV system:

- A deployable STTV system can provide the real time sensor and FBCB2 situation awareness information required by an armored vehicle commander.
- A deployable STTV helmet-mounted display alone (800x600 pixel color display and helmet mount without sensor and image processor) satisfies all the requirements of

the vehicle commander for FBCB2 situation awareness information while standing in the hatch with the head outside the vehicle. This provides a solution to meeting the most urgent needs of the vehicle commander for situation awareness information.

- A helmet-mounted display with a wider field of view (e.g., 40°x30° or greater) can provide more situation awareness sensor information to the vehicle commander than the 26°x19° FOV Land Warrior Display. A larger field of view display would better match the field of view of the cameras in the panoramic camera (56° horizontal FOV) and would not throw away as much useful sensor information as the 26°x19° Land Warrior display. Helmet-mounted displays are limited to approximately 40° monocular field of view by optics design considerations. Panel-mounted displays can have fields of view greater than 40° by tiling multiple displays. Panel-mounted displays, however, can not be used to display the FBCB2 information to the commander when he is standing in the hatch with his head outside the vehicle.
- Adding a visible CCD camera to the gimbal containing the IR sensor can provide higher resolution CCD imagery with less latency, and less IR-to-visible sensor parallax, than the imagery provided by the visible panoramic camera in the prototype STTV system. A visible CCD camera on the gimbal also allows greater flexibility in selecting a higher resolution (e.g., 1320 x 480 pixels) monochrome CCD camera, or a color CCD camera, with less expense than a panoramic camera approach. One can also add a zoom lens to the camera that provides higher resolution imagery when zoomed, in contrast to the electronic zoom on the panoramic camera, which decreases in resolution when zoomed. Finally, image processor throughput can be substantially reduced by eliminating the need for multi-camera image warping and mosaicing, leaving more processor throughput for target tracking functions. This might make it possible to use a lower cost commercial PC computer for target tracking instead of the relatively expensive PVT-200 processor. The only penalty of this approach is the inability of the gimbaled camera to display two different fields of view simultaneously (e.g., to the vehicle commander and a squad leader). This is not much of a penalty because displaying two different fields of view at the same time requires additional processor throughput that is not currently available in the prototype STTV system. Also, it is possible minimize this penalty by designing the system control to allow the vehicle commander to pass the sensor panning control to the squad leader prior to exiting the vehicle and then to re-establish his own panning control after an exit is made.
- Adding a second microbolometer IR sensor with a 40°x30° FOV to the gimbal already containing a microbolometer sensor with a 15.5°x11.6° FOV can provide a dual field of view IR sensor with 8-12 μm sensitivity and higher resolution than an electronic zoom, and possibly at lower cost and smaller size than single IR sensor with a dual field of view lens having 8-12 μm transmissivity.

Section 5.0 Recommendations

It is recommended that the prototype STTV system be evaluated on a moving armored vehicle with real FBCB2 information. This will allow evaluation of the helmet-mounted display in the mode where the commander is standing in the hatch with his head outside the vehicle as well as the mode where the commander is seated inside the vehicle looking at sensor information. Operation on a moving armored vehicle requires improvement of the head tracker, which may be accomplished by adding an optical head tracker to the current STTV inertial head tracker. If evaluation cannot be performed on an armored vehicle having FBCB2 information, then consideration should be given to evaluating the system on an armored vehicle without FBCB2 information as a test of the STTV sensor capabilities.

It is also recommended that development proceed on a lower cost and higher performance deployable STTV system having the following improvements over the prototype STTV system:

- Retain the helmet mount, commander's control panel, and gimbaled IR microbolometer sensor.
- Improve the monochrome 26°x19° FOV 640x480 pixel prototype helmet-mounted display to a color 40°x30° FOV 800x600 pixel helmet-mounted display.
- Add a color 749x483 pixel CCD camera with 40°x30° FOV zoom lens to the gimbal.
- Improve the IR sensor from a 640x480 pixel microbolometer sensror with a 15.5°x11.6° FOV lens to a 640x480 pixel microbolometer sensor with a 40°x30° lens when the larger microbolometer sensors become available.
- Add an optical tracker to the current inertial tracker to make the tracker more metal tolerant.
- Substitute a PC-based processor for the PVT-200 processor for target tracking and system control.
- Add a cursor to the commander's control panel to allow preparation of FBCB2 reports while standing in the hatch with head out.
- Add a switch to the commander's control panel for temporarily passing the gimbal panning control to a squad leader on the vehicle.
- Evaluate the improved STTV system on moving armored vehicle with real FBCB2 information.

This document reports research undertaken at the U.S. Army Soldier and Biological Chemical Command, Soldier Systems Center, and has been assigned No. NATICK/TR-02/005 in a series of reports approved for publication.

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Appendices

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Appendix A
STTV System Requirements Specification

Sensor and Guidance Products Divison

Honeywell

[X]	MINNEAPOLIS, MN	FSCM 94580
[ ]	ST. PETERSBURG, FL	FSCM 09128

SPECIFICATION NO. DSXXXXX-01

TYPE: [X] SYSTEM [ ] DEVELOPMENT [ ] MATERIAL [ ] ENGINEERING [ ] PRODUCT [ ] PROCESS [ ] OTHER

TITLE: System Requirements Specification for a See-Through Tank Visualization System

	SIGNATURES	TITLE	DATE
PREPARED BY:	Ron Belt	Pr. Development Engineer	
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1. SCOPE

This specification establishes the user needs for a See Though Tank Visualization System (STTV). The user needs define the performance and interface features of the required system, but do not specify the system design, partitioning, or construction details. The user needs were obtained from interviews with Army personnel who have working experience with the Army vehicles to be affected by the STTV system.

2. REFERENCE DOCUMENTS

The documents attached in Appendix A provide reference material which supports the user needs specified in this document.

3. SYSTEM REQUIREMENTS / USER NEEDS

3.1 System Objectives

The STTV system shall provide increased situation awareness for a vehicle commander by providing a 360° panoramic view of the vehicle's surroundings, or the imagery from a UAV, on a helmet-mounted display while inside the vehicle or while standing in an open hatch. It shall also allow the vehicle commander to view the digitized battle management information (normally) displayed on an embedded tactical display, or on an applique tactical display, while standing in an open hatch.

3.1.1 System User

The STTV system shall be used by the commander of an armored vehicle to increase his situation awareness in a battlefield environment. The STTV system is not intended for use by the vehicle driver, gunner, loader, or passengers, although specific parts of the system may be applied to this purpose; e.g., a helmet-mounted display for a squad leader to reconnoiter the area surrounding the vehicle prior to exiting the vehicle for dismounted operations.

3.1.2 Occasion of Use

The STTV system shall be usable by the commander either while he is inside the vehicle turret (buttoned up) or while he is standing in the open hatch. The system is not intended to be installed in or on the vehicle's hull, where it would need to pass through the vehicle's slip rings. (Current vehicle slip rings are not designed to handle the additional high bandwidth STTV sensor data).

When applied to vehicles in development, where the commander may be located in the hull and the vehicle's sensors located on a remotely operated turret (e.g., on the FSCS, FCV, or Crusader vehicles), the STTV sensor should be located on the turret and the display used by the commander in the hull. In these cases the vehicle's slip rings can be designed to handle the high bandwidth STTV sensor data.

During system development and demonstration the STTV system may be mounted on an M113

hull for development cost minimization and expediency purposes. The M113 used for this purpose should not have a turret.

3.1.3 System Applications

The STTV system shall be used by the vehicle commander for the following applications:

1) detection of terrain hazards in the vehicle's path to help the commander aid the driver in recognizing hazardous situations that could immobilize the vehicle or cause damage to the vehicle and its crew,
2) detection of nearby friendly forces and environmental structures to maintain orderly movement and to avoid damage to the vehicle, friendly forces, or man made structures,
3) detection of nearby ground threats to allow protective measures to be employed,
4) display of information from the commander's independent viewer and tactical display while standing in an open hatch to allow immediate notification of incoming reports and to assist in preparing outgoing reports without the need to duck back into the vehicle ,
5) display of UAV imagery while inside the vehicle or while standing in an open hatch.

The STTV system is not intended to be used for the following purposes:

1) by the vehicle commander or gunner as a primary target acquisition sensor,
2) by the vehicle driver as a driver's vision enhancer,
3) by the vehicle loader (or autonomously) as an detector of enemy aircraft or incoming missiles,
4) by a vehicle crewman as a vehicle maintenance aid,
5) by a vehicle passenger as a reconnoitering aid prior to exiting the vehicle for dismounted operations.

While the STTV system is not designed for these purposes, it is possible that specific parts of the system may be applicable to one or more of these purposes; e.g., a helmet-mounted display for squad leader reconnoitering prior to exiting the vehicle for dismounted operations.

3.1.3.1 Driver Assistance Application

The following needs are associated with the commander assisting the driver to avoid immobilization of the vehicle or damage to the vehicle and/or its surroundings.

3.1.3.1.1 Road Hazard Detection

The STTV system shall aid the commander in detecting drop-offs of three feet or more, unstable terrain, muddy holes, swampy terrain, or water obstacles that lie in the vehicle's path so that damage to the vehicle or vehicle immobilization may be avoided.

The driver of an armored vehicle is sometimes unable to detect hazardous situations in the vehicle's path because of his low vantage point on the vehicle, or because his attention is diverted to other locations in his field of view. This can lead the driver to encounter the hazardous obstacles, causing the vehicle to get stuck or to roll over. Such rollovers can lead to

injury of the crew, or even death. This problem is especially acute while driving at night or when the driver's vision aids have low contrast caused by smoke, haze, fog, or small thermal differences in the scene.

As a result, the vehicle commander is trained to stand in the open hatch while the vehicle is moving and to help search for hazardous situations so that he can assist the driver in avoiding them. The commander may use his unaided vision in the daytime and (third generation) night vision goggles at night. When contact with the enemy is immanent, the commander is taught to button up the hatch for greater protection. This leaves the commander with only his vision blocks for road hazard detection. At night, when approaching the enemy, the vision blocks are usually covered up to prevent detection of the vehicle's internal lights through the vision blocks by the enemy. This leaves the vehicle commander with no way of searching for road hazards, except for using the commander's independent target acquisition sensor, if one exists on the vehicle. This sensor usually has a small field of view (10°x7° or smaller), which is too small for efficient road hazard detection. The STTV system with its larger field of view can provide the commander with a more efficient capability for day or night detection of hazardous road conditions.

3.1.3.1.2 Detection of Nearby Vehicles, Dismounted Troops, and Man Made Structures

The STTV system shall aid the commander in detecting nearby armored vehicles, wheeled vehicles, and dismounted troops, as well as natural and manmade structures such as trees, buildings, transmission lines, radio antennas, etc., so that damage to nearby objects may be avoided.

The vehicle commander is ultimately responsible for damage to the vehicle, and for damage done by the vehicle to nearby structures, vehicles, and dismounted troops. When an armored vehicle is in motion, the commander is trained to be on constant lookout for nearby objects such as dismounted troops, vehicles, trees, transmission line towers, radio towers, telephone poles, bridges, buildings, and associated manmade structures, and to issue concise orders to the driver and gunner (such as "DRIVER RIGHT", "GUNNER LEFT") to avoid encountering these objects with the vehicle hull, turret, or gun. In order to issue the proper orders, the commander must be able to see the objects along with the vehicle direction of motion and the turret-hull orientation.

While some vehicles, such as the M1A2 Abrams and M2A2 Bradley, may have a turret-hull orientation indicator inside the turret, the commander is trained to avoid using it because this takes his attention away from the nearby objects. The commander, instead, is trained to stand in the open hatch where he can observe directly and simultaneously both the objects to be avoided and the vehicle's direction of motion and turret-hull orientation. On some vehicles, such as the M1A2 Abrams, it is impossible to see the hull while standing in the commander's open hatch, so the commander must infer the hull's orientation from the motion of the ground as it passes by. The commander may use his unaided vision in the daytime and (third generation) night vision goggles at nighttime for assistance in detecting nearby objects.

When the enemy has been sighted, the commander is taught to button up the hatch for greater protection. This leaves the commander with only his vision blocks for nearby object detection.

At night, when approaching the enemy, the vision blocks are usually covered up to prevent detection of the vehicle's internal lights by the enemy. This leaves the commander with no way of searching for nearby vehicles, dismounted troops, buildings, and related structures, except for using the commander's independent target acquisition sensor, if one exists on the vehicle. This sensor usually has a small field of view (10°x7° or smaller), which is too small for efficient searching for nearby objects. The STTV system with its larger field of view can provide the commander with a more efficient capability for day or night detection of nearby objects.

3.1.3.1.3 Driver Backup Assistance

The STTV system shall aid the commander in seeing what is behind the vehicle so that proper direction can be given to the vehicle driver while backing up in order to avoid a potential hazard or nearby object.

On most armored vehicles, the driver's vision is limited to a forward 180° field of regard symmetric with the vehicle's centerline. Vision to the rear is usually obstructed by the vehicle's turret. Therefore, the driver must have assistance from the vehicle commander while backing up the vehicle to avoid potential road hazards or nearby objects. The STTV system can help the commander to see the area behind the vehicle and to issue the proper assistance to the driver while the commander is standing in the open hatch or while the vehicle is buttoned up.

3.1.3.1.4 Requirements Supporting Driver Assistance Application

3.1.3.1.4.1 Field of Regard

The STTV sensor shall have a field of regard of 360 degrees around the vehicle.

3.1.3.1.4.2 Field of View

The STTV system shall provide the commander the widest possible field of view for the efficient detection of road hazards, nearby objects, turret-hull orientation determination, and rear view visualization so that he can issue the proper orders to the driver.

Experience has shown that the widest practical field of view achievable with a helmet mounted display is approximately 40°x30° for a single eye. This limitation is caused by optical design considerations such exit pupil size, focal length, and interference with vision from the other eye. Experience also shows that a helmet-mounted display should provide an image that is one-to-one with the real world to avoid problems with user disorientation due to the scene moving faster or slower than the head motion. This implies that the sensor field of view must be approximately 40°x30° to match the display field of view. These considerations apply whether or not the display is see-through or non-see-through.

3.1.3.1.4.3 Focus

The STTV sensor shall keep in focus objects at a distance of 15 feet to infinity while operating as a commander's driving assistance aid.

3.1.3.1.4.4 Detector Wavelength

The STTV sensor shall be capable of detecting road signs, drop-offs of 3 feet or more, unstable terrain, muddy holes, swampy terrain, or water obstacles that lie in the vehicle's path in either daylight conditions or in overcast starlight conditions in the presence of smoke and haze.

Experience has shown that sensors with a response in the 8-12 µm region provide the best performance under conditions of smoke, haze, and fog. Therefore, the STTV sensor shall have a sensor response in this region.

3.1.3.1.4.5 Latency

The information on the STTV display must not lag behind the normal head motion.

Experience has shown that a helmet mounted display system, consisting of the sensor, tracker, and display electronics, must have a total system latency of less than 60 milliseconds in order to avoid problems with system lag.

3.1.3.2 Ground Threat Detection Application

The STTV system shall aid the commander in the detection of nearby ground threats to allow protective measures to be employed.

When an armored vehicle is in motion, the vehicle commander is trained to be on constant lookout for nearby ground threats, such as enemy troops and vehicles. The commander is trained to look all around the vehicle out to a distance of approximately 400 yards, for enemy troops and vehicles. He is especially trained to look for crouching troops in the tree lines at the edge of the battlefield. At times, he will share this responsibility with the loader on the M1A2 or the gunner on the Bradley. In this case, the loader will look in a 180° sector on his side of the vehicle, and the commander in a 180° sector on his side of the vehicle. The loader will also be responsible for airborne threats, and the commander for driver assistance.

The commander may use his unaided vision in the daytime and (third generation) night vision goggles at night. When contact with the enemy is immanent, the commander is taught to button up the hatch for greater protection. This leaves the commander with only his vision blocks for nearby ground threat detection. At night, when approaching the enemy, the vision blocks are usually covered up to prevent detection of the vehicle's internal lights through the vision blocks by the enemy. This leaves the vehicle commander with no way of searching for nearby ground threats, except for using the commander's independent target acquisition sensor, if one exists on the vehicle. This sensor usually has a small field of view (10°x7° or smaller), which is too small for efficient detection of nearby ground threats. The STTV system with its larger field of view can provide the commander with a more efficient capability for day or night detection of nearby ground threats.

The most demanding need when detecting ground threats is detecting a crouching human being at 400 yards of the vehicle, especially at night in conditions of haze, fog, or smoke.

3.1.3.2.1 System Requirements Supporting Ground Threat Detection Application

3.1.3.2.1.1 Field of Regard

The STTV sensor shall have a field of regard of 360 degrees around the vehicle.

3.1.3.2.1.2 Field of View

The STTV system shall provide the commander the widest possible field of view for the detection of nearby ground threats.

Experience has shown that the widest practical field of view achievable with a helmet mounted display is approximately 40°x30° for a single eye. This limitation is caused by optical design considerations such exit pupil size, focal length, and interference with vision from the other eye. Experience also shows that a helmet-mounted display should provide an image that is one-to-one with the real world to avoid problems with user disorientation due to the scene moving faster or slower than the head motion. This implies that the sensor field of view must be approximately 40°x30° to match the display field of view. These considerations apply whether or not the display is see-through or non-see-through.

3.1.3.2.1.3 Resolution

The STTV system shall be capable of detecting crouching human-size objects at a distance of 400 yards from the vehicle.

3.1.3.2.1.4 Focus

The STTV sensor shall keep in focus objects at a distance of 15 feet to infinity while helping the commander to detect ground threats around the vehicle.

3.1.3.2.1.5 Detector Wavelength

The STTV sensor shall be capable of detecting crouching human-size objects at a distance of 400 yards from the vehicle in either daylight conditions or in overcast starlight conditions in the presence of smoke, fog, and haze.

Experience has shown that sensors with a response in the 8-12 μm region provide the best performance under conditions of smoke, fog, and haze. Therefore, the STTV sensor shall have a response in this region.

3.1.3.2.1.6 Latency

The information on the STTV display must not lag behind the normal head motion.

Experience has shown that a helmet mounted display system, consisting of the sensor, tracker, and display electronics, must have a total system latency of less than 60 milliseconds in order to avoid problems with system lag.

3.1.3.3 Display of Data from Commander's Viewer and Tactical Display While in Open Hatch

The STTV system shall display information from the commander's independent viewer and tactical display while the commander is standing in the open hatch to provide the commander immediate notification of incoming reports and to assist him in preparing outgoing reports without the need to duck back into the vehicle.

When the vehicle commander is standing in the open hatch for purposes of driver assistance or vehicle protection, he is unable to see his independent viewer display and tactical display. This means that he can miss the arrival of a battalion commander's incoming order, or another vehicle's enemy contact report, on the tactical display. It may also mean that he must duck back into the vehicle to fill out his own enemy contact report, which can take his attention away from his duties of driver assistance and vehicle protection. Sometimes, on an M1 Abrams, the loader is able to notify the vehicle commander of an incoming report and to help him with the preparation of new reports. But there is no alternative for the commander than to duck back down into the turret in order to read an incoming report.

Similarly, when the vehicle commander is standing in the open hatch, he is unable to see his independent thermal viewer display. This means that he cannot use easily his independent thermal viewer to check out a suspicious area for targets, and may miss an important opportunity to spot the enemy first before he is spotted.

The following needs are associated with the display of information from the commander's independent thermal viewer and tactical display while standing in an open hatch.

3.1.3.3.1 FLIR Sensor Display

The STTV display shall be capable of displaying the real time imagery from an HTI second generation FLIR, such as the CITV on the M1A2 Abrams SEP vehicle, or the CIV on the M2A3 Bradley vehicle.

The HTI second generation FLIR is the standard FLIR that will be used on all future armored vehicles and armored vehicle upgrades. While some vehicles may still use a first generation FLIR, or no FLIR, at this time, nearly all vehicles will be upgraded to the HTI second generation FLIR standard. Therefore, by the time the STTV system is available, most FLIR's will be HTI second generation FLIR's.

3.1.3.3.1.1 FLIR Display Resolution

The STTV display shall be capable of displaying all or part of the HTI second generation FLIR 1315x480 pixel imagery at 30 frames/sec. Modified RS-170 timing will be used.

3.1.3.3.1.2 FLIR Display Color

The STTV display shall be capable of displaying the monochrome imagery from an HTI second generation FLIR sensor.

3.1.3.3.2 Tactical Display

The STTV display shall be capable of displaying the tactical information, such as reports and color maps, from an embedded vehicle FBCB2 tactical display or from a TRW Applique+ display.

3.1.3.3.2.1 Tactical Display Resolution

The STTV display shall be capable of displaying all of the 800x600 pixel data of the tactical display at a 50 Hz refresh rate. XVGA timing will be used.

3.1.3.3.2.2 Tactical Display Color

The STTV display shall be capable of displaying the color map data displayed an embedded vehicle FBCB2 tactical display or from a TRW Applique+ display.

3.1.3.4 Display of UAV Information

The STTV system shall be capable of displaying UAV imagery on the commander's helmet-mounted display while inside the vehicle or while standing in an open hatch.

3.1.3.4.1 RF Data Link Interface

The STTV system shall provide an RF receiver capable of receiving the real time sensor data from a UAV.

3.1.3.4.2 UAV Display Resolution

The STTV display shall be capable of displaying the real-time 640x480 pixel imagery information from a UAV at 30 frames/sec. Modified RS-170 timing will be used. The STTV display shall also be able to display the annotated still images received over the FBCB2 tactical data network.

3.1.3.4.3 UAV Display Color

The STTV display shall be capable of displaying the real-time monochrome imagery from a UAV sensor or the annotated still images received over the FBCB2 tactical data network.

3.2 Vehicle Compatibility

The STTV system shall be capable of operating on multiple types of armored vehicles. Multiple vehicle compatibility shall be achieved by a modular design which permits tailoring the STTV system to the vehicle's needs: e.g., by selecting a subset of the modules for a fielded vehicle needing only a helmet-mounted display or by selecting the complete set of sensor, processor, and UAV imagery receiver modules for a new vehicle in development.

3.2.1 Vehicle Types Supported

The STTV system shall be capable of operating on the following vehicle types in the Army inventory or currently in development:

1) M1A1 Abrams
2) M1A2 Abrams
3) M1A2 SEP Abrams
4) M2A2 ODS Bradley Infantry Vehicle
5) M2A3 Bradley Infantry Vehicle
6) M3A2 ODS Bradley Cavalry Vehicle
7) M3A3 Bradley Cavalry Vehicle
8) M113 Infantry Vehicle
9) M109 Paladin (Howitzer)
10) M88A2 Hercules (Armored Recovery Vehicle)
11) Wolverine (Heavy Assault Bridge)
12) LAV-25 (Light Armored Vehicle)
13) AAAV (Advanced Amphibious Armored Vehicle)
14) XM2001Crusader (Howitzer)
15) FSCS / Tracer (Future Scout and Cavalry System)
16) XM8 AGS (Armored Gun System)
17) XM4 C^2V (Command and Control Vehicle)
18) FCV (Future Combat Vehicle)
19) FIV (Future Infantry Vehicle).

3.2.2 Vehicle-Related System Requirements

3.2.2.1 Sensor Mounting Location

The STTV sensor shall be mounted on the vehicle turret. The STTV sensor should not obstruct the operation of existing equipment on the turret, such as sensors, machine guns, or missile launchers. The STTV sensor should not be higher than the top of the open hatch on the vehicle. The STTV sensor shall consist of a single package capable of 360° operation, if possible, but shall be capable of being separated into smaller units having smaller fields of view and placed at multiple locations on the outside of the turret, if required.

3.2.2.2 Display Electronics Location

The STTV display electronics shall be mounted inside the vehicle turret. The STTV display electronics shall not interfere with the operation of other functions within the turret.

3.2.2.3 Display Controls Accessibility

The STTV display controls shall be accessible to the commander while he is seated inside the vehicle or while he is standing in the open hatch.

3.2.2.4 Display Mounting on Helmet

The STTV display shall be mountable on a standard DH-132 Combat Vehicle Crew (CVC) helmet per MIL-H-44117. The display shall be mountable in such a manner as to allow either left eye or right eye operation. The display shall have two positions on the helmet: an operating position and a stow position. In the stow position the display shall be turned off. In the operating position the display mount shall permit both a look over and a look under mode of operation. The display mount shall not interfere with the use of:

1) personal eyeglasses,
2) sand, wind , and dust goggles, and the storage of these goggles on the top of the helmet,
3) NBC mask,
4) head rests while using any sights inside the vehicle,
5) moving through the open hatch in either direction.

3.2.2.5 Display Cable

The STTV display unit shall have a cable length and flexibility that permits normal motion of the commander while inside the vehicle or while standing in an open hatch. Normal motion shall include sitting down, standing on the seat, turning in any direction, and facing in any direction, including rearward, while standing on the seat.

3.2.2.6 Quick Disconnect Connector

The STTV display cable shall have a quick disconnect connector that allows rapid egress from the vehicle without pulling on a lanyard. The maximum separation force of the quick disconnect connector shall be 10 lbs or less.

3.2.2.7 Light Leakage

Light leakage around the helmet-mounted display shall be undetectable by the naked eye at ranges beyond 10 meters and undetectable with AN/PVS-5 or AN/PVS-7 night vision goggles beyond 25 meters.

3.3 Composite STTV System Performance Requirements

The STTV system shall include a sensor function and a display function. The composite performance requirements for these functions that enable them to support all the needs identified above are listed in the following subsections.

3.3.1 Sensor Performance

The STTV sensor shall have the following capabilities:

- 360° field of regard
- 40°x30° FOV
- in focus ≥ 15 feet
- 8-12 μm wavelength
- ≥170° /sec slew rate.

3.3.2 Display Performance

The STTV display shall have the following capabilities:
- monocular
- non see-through
- 800x600 pixels
- 40°x30° FOV
- color.

3.3.3 System Performance

The STTV system shall have the following capabilities:
- able to detect human targets at 400 yards
- < 66 msec system latency
- slew to cue capability.

3.3.4 Human Factors Requirements

The STTV system shall meet the following human factors requirements:
- no illness caused by imagery motion on the display
- controls located on the vehicle in easily accessible places
- no hazardous materials or dangerous modes of use
- helmet with display causes no discomfort or strain on user's head or neck.

3.4 Acronyms

CITV	Commander's Independent Thermal Viewer
CIV	Commander's Independent Viewer
CVC	Combat Vehicle Crew
FBCB2	FXXI Battle Command, Brigade and Below
FCV	Future Combat Vehicle
FLIR	Forward Looking Infra Red
FOR	Field of Regard
FOV	Field of View
FSCS	Future Scout and Cavalry System
HTI	Horizontal Technology Integration
HMD	Helmet Mounted Display
Hz	Hertz
ICCD	Intensified Charge Coupled Device
IHAS	Integrated Helmet Assembly Subsystem
IVIS	Inter Vehicular Information System
NBC	Nuclear Biological Chemical
NFOV	Narrow Field of View
ODS	Operation Desert Storm
SEP	System Enhancement Program
SVGA	Super Video Graphics Adapter
STTV	See-Through Tank Visualization

TBD	To Be Determined
UAV	Unmanned Aeronautical Vehicle
VGA	Video Graphics Adapter
WFOV	Wide Field of View

Appendix B
STTV Prototype Development Specification

Sensor and Guidance Products Divison

Honeywell

X	MINNEAPOLIS, MN	FSCM 94580
	ST. PETERSBURG, FL	FSCM 09128

SPECIFICATION NO. DSXXXXX-01

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TITLE: Development Specification for a See-Through Tank Visualization System

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SPECIFICATION NO. DSXXXXX-01

1. SCOPE

This specification establishes the design for a See Though Tank Visualization System (STTV). The STTV system shall provide increased situation awareness for a vehicle commander by providing a 360° panoramic view of the vehicle's surroundings, or the imagery from a UAV, on the Mounted Warrior helmet-mounted display while inside the vehicle or while standing in an open hatch. It shall also allow the vehicle commander to view the digitized battle management information received from an integrated vehicle or applique system while standing in an open hatch. The STTV system shall be capable of operating on multiple vehicle types. Multi-vehicle compatibility shall be achieved by a modular design which permits tailoring the STTV system to the vehicle's needs; e.g., by selecting a subset of the modules for a fielded vehicle needing only a helmet-mounted display or by selecting the complete set of sensor, processor, and UAV imagery receiver modules for a new vehicle in development.

The design specified in this document is intended to be an accurate description of a demonstration system that shows the feasibility of meeting the user's STTV system requirements, but that uses surrogate sensors and helmet mounted displays of lower performance due to funding constraints. Similarly, due to the unavailability of an M1A2 Abrams or M2A2 Bradley, a surrogate M113 demonstration vehicle will be used that lacks a second generation FLIR sensor and tactical display. Therefore, the interfaces to these functions will not be provided.

Figure 1.1 See-Through Tank Visualization System Sensor Unit

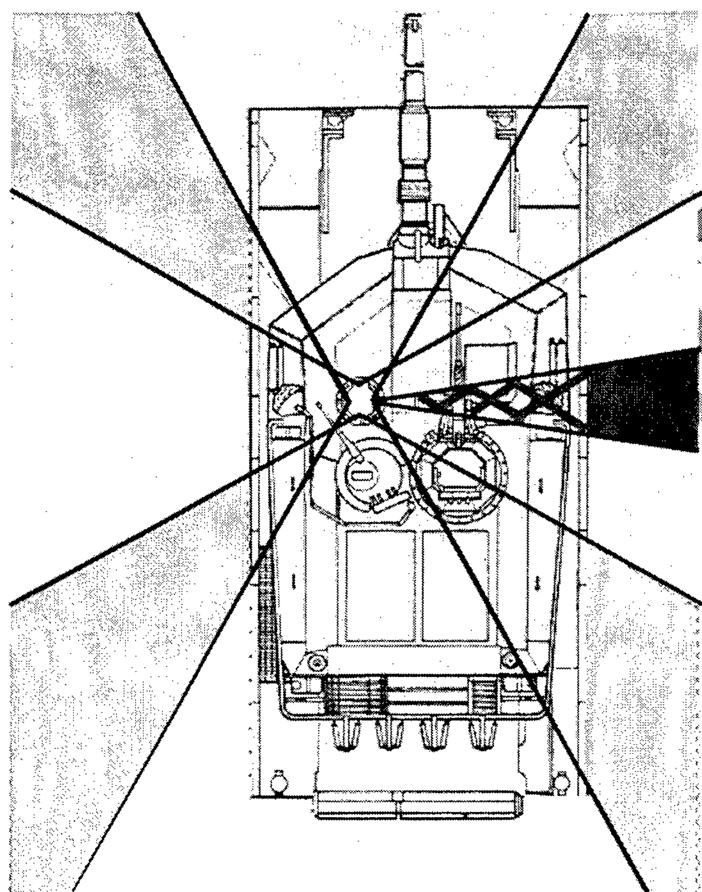

Figure 1.2 See-Through Tank Visualization System Fields of View

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent specified herein. In the event of a conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered the superseding requirement.

2.1 Government Specifications

System Requirements Specification for a See-Through Tank Visualization System, Honeywell Inc, 6 November 1998

2.2 Honeywell Specifications

Land Warrior IHAS Specification, Honeywell Inc, 12 January 1998

3. Requirements

3.1 System Description

The See Though Tank Visualization System shall consist of the following components as shown in Figure 3.1:

a) panoramic sensor unit
b) gimbaled IR sensor unit
c) image processor
d) power supply
e) RS-232 switch
f) developer's control panel
g) helmet assembly
h) helmet-mounted display
i) display control module
j) head tracker inertial measurement unit
k) head tracker signal processor
l) commander's conrol panel
m) squad leader's joystick control.

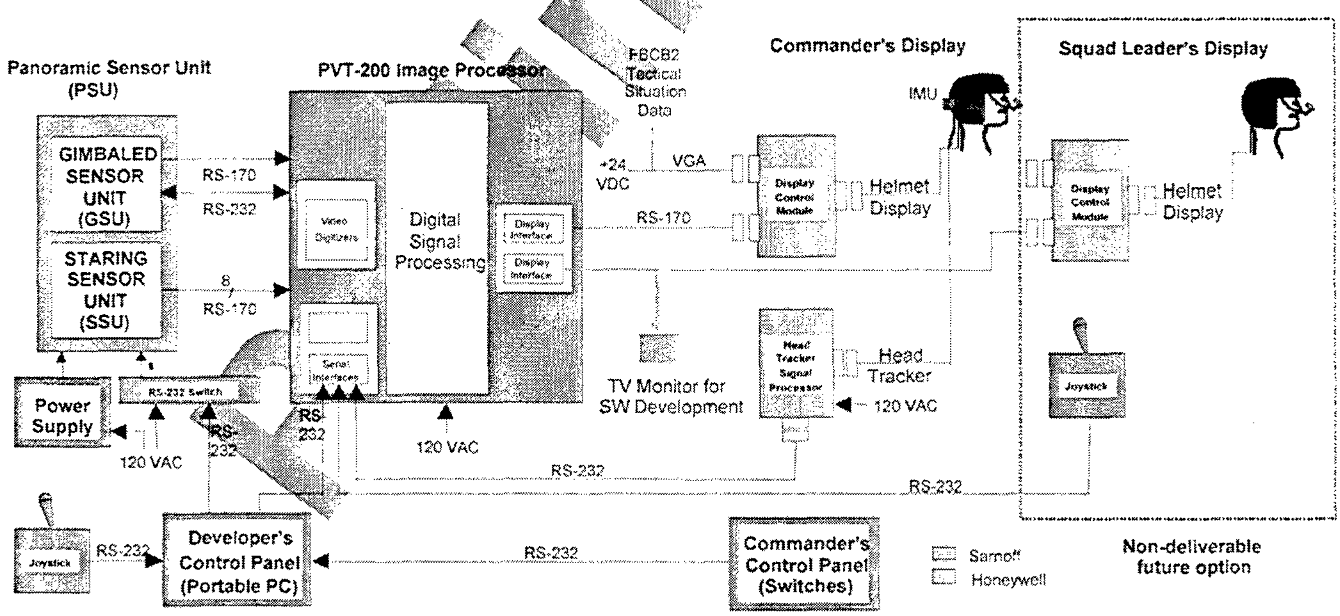

Figure 3.1 See-Through Tank Visualization System Components

3.2 STTV System Module Specifications

3.2.1 Panoramic Staring Sensor Unit

The panoramic staring sensor unit shall provide the vehicle commander a low latency 360° view of the vehicle's surroundings in either day or night illumination conditions. The sensor unit shall consist of eight monochrome visible CCD cameras with each camera having 659x494 pixels and a 6 mm autoiris lens with a field of view of 56°(H) x 42°(V). The cameras shall be arranged to provide 360° panoramic field of view wherein all the cameras have the same focal point to eliminate parallax between adjacent cameras. Each camera shall provide a horizontal field of view of 45° encoded into 512 pixels. The vertical field of view shall be 42°, tilted down 7° from the horizontal (i.e, 14° above the horizontal and 28° below the horizontal). The cameras shall have an interlaced RS-170 output with all the pixels in the same frame illuminated within the same integration time to eliminate image offset between fields that causes motion blur. The cameras shall have automatic gain control circuits and auto iris lenses to allow operation over a wide range of ambient illumination. The cameras shall have an RS-232 interface that allows changing the camera integration time and gain settings. The panoramic staring sensor shall provide an unobstructed 360° view of the vehicle's surroundings without obstructing other turret functions such as FLIR sensors and machine guns. The panoramic staaring sensor shall allow the detection of terrain obstacles and hazards in the vehicle's path, such as gullies and drop-offs, and the detection of human-size threats at a distance of 500 yards.

3.2.2 Gimbaled IR Sensor Unit

The gimbaled IR sensor unit shall provide the commander a higher resolution view of the vehicle's surroundings in either day or night illumination conditions at the expense of increased latency. The sensor shall consist of a 320x240 pixel or greater microbolometer LWIR sensor with a horizontal field of view of 15.5° and a vertical field of view of 11.5°. The sensor shall be mounted on a gimbal that allows slewing in both the azimuth and elevation directions. The gimbal controller shall permit head-tracked scanning with a slew rate of 170° per second in both the azimuth and elevation directions. The sensor shall permit the detection of terrain obstacles and hazards in the vehicle's path and the detection of human-size threats at a distance of 500 yards. The sensor with gimbal shall have a diameter of 12 inches or less and a height of 16 inches or less when mounted on the vehicle turret. This unit may be replaced by the CITV when used on an M1A2 Abrams or by the CIV when used on the M2A3 Bradley or M3A2 Scout vehicle.

3.2.3 Image Processor Unit

The image processor unit shall accept real-time monochromatic imagery data from the STTV panoramic staring sensor modules, and the STTV high resolution scanned sensor unit, and shall provide processed imagery to the helmet-mounted display unit. The image processor unit shall be capable of performing the following image processing functions without reconfiguration:

1) Controlling the panning and tilting of the 360° FOV panoramic staring sensor unit to produce a visible TV image stream in the direction of the commander's current line of sight. This involves translating the head tracker output signal into a current line of sight direction, selecting the two camera outputs nearest the current line of sight direction, warping their image streams to the new line of direction, mosaicing the resulting image streams to create a single new image stream, and blending the image junction in the new image stream to form a seamless image in the current line of sight direction.
2) Controlling the panning and tilting of the gimbaled IR sensor unit to produce an IR image stream in the direction of the commander's current line of sight,
3) Aligning the lines of sight of the visible and IR sensors to the head tracker line of sight by mapping their forward-most line of sight (zero degrees azimuth relative to the turret) to the head tracker line of sight when the head tracker is being aimed to the front of the turret (zero degrees azimuth).
4) Black hot / white hot selection of the IR imagery,
5) Alignment and superposition of the narrow field of view IR imagery with the wide field of view visible TV imagery to produce a multisensor fused image with higher resolution in the foveal region,
6) Electronic zoom (in and out from the 1:1 magnification) of the displayed imagery,
7) Reticle size control (larger and smaller from a standard size reticle). The reticle shape be easily changeable by modifying a bit-mapped software file.
8) Moving target tracking of an object previously designated by the contents of a reticle box,
9) Rear view mode, whereby the line of sight of the sensor(s) currently being displayed is immediately switched to the direction 180° in back of the current head position to show the imagery toward the rear in a non-left/right inverted fashion.
10) Slew-to-cue mode, whereby the user can immediately slew the displayed imagery to the target being tracked by the IR sensor instead of continuing to look in the direction of the current head position (i.e., the display of the target is decoupled from the head tracker position). This mode simulates a vehicle's turret being rotated by the gunner to a new target previously selected by the commander.
11) Re-designation of the target being tracked, whereby reducing the size of the target box while a target is being tracked and re-selecting the tracking function will cause the moving target tracker to track the new features in the smaller reticle box.
12) Second generation FLIR image warping, whereby the processor will warp the 1:1.5 pixel ratio second generation FLIR imagery applied to the IR sensor input to a 1:1 pixel ratio required by a commercial AMEL display. This will allow the second generation FLIR imagery to be displayed on a commercial display without image distortion in the horizontal direction. And, finally,
13) Control panel integration, whereby the control signals produced by the commander's control panel are mapped into the software commands for controlling the sensor and processor functions.

The image processor unit shall fit into a 6U VME chassis. It shall have the following image data inputs and outputs:

a) eight RS-170 inputs for imagery from the panoramic staring sensor modules (monochrome 659x494 pixels at 30 frames per second),
b) one RS-170 input for imagery from the scanned high resolution sensor unit (monochrome 320x240 pixels at 30 frames per second),
c) one RS-170 input for imagery from an HTI second generation FLIR sensor unit (monochrome 1315x480 pixels at 30 frames per second),
d) one RS-170 output for imagery to the commander's helmet-mounted display, and
e) one RS-170 output for imagery to a tape recorder, video monitor, or alternate helmet-mounted display.

The image processor unit shall accept an RS-232 control input from the developer's control panel that allows the system control modes :

a) selection of the imagery source,
b) selection of the display mode:
   1) either a head tracker mode in which the user can read out a subset of the 360° panoramic image in the database using a head tracker or manual joystick for a pan and tilt control, or
   2) one of four manually selected views of the data in the image database, and
c) designation of a target for a slew to cue mode.

The image processor unit shall also accept an RS-232 control input from the commander's head tracker signal processor unit and a second RS-232 control input from a squad leader's manual joystick that allow the selection of the field of view corresponding to the user's desired line of sight (LOS).

The image processor shall provide an RS-232 control output to the gimbaled sensor that allows the gimbaled sensor to slew in response to head motion and to track moving objects.

3.2.4 Power Supply Unit

The power supply unit shall generate all the voltages required by the STTV system components. The power supply unit shall be powered by 110 VAC which, in turn, shall be supplied by a 110 VAC power inverter that is capable of operating from a 28 volt vehicle power source per MIL-STD-1275. (Note: This requires the power inverter to operate over the range of 16VDC to 30 VDC).

3.2.5 RS-232 Switch

An RS-232 switching unit shall be provided that allows the developer's control panel to send control commands to each of the eight CCD cameras via an RS-232 link.

3.2.6 Developer's Control Panel

A developer's control panel shall be provided in the form of a portable PC that enables controlling the image processor via an RS-232 link using a keyboard and mouse. The developer's control panel shall also permit controling the camera settings during development via an RS-232 link.

3.2.7 Helmet Assembly

The helmet assembly shall consist of a standard DH-132 CVC helmet and liner (MIL-H-44117A), with a standard M-138/G microphone and MK-1697/G headset. When used with a head tracker, the helmet assembly shall include a head tracker sensor mounted on the side of the helmet opposite to the display. No new holes shall be required in the helmet to mount the tracker sensor. The total weight of the helmet assembly with head tracker and one foot of intercom cable shall be less than TBD pounds. The center of gravity shall lie no more than TBD mm from the tragion in the front/back and side/side directions.

3.2.8 Helmet-Mounted Display

The helmet-mounted display shall be a Mounted Warrior compatible display having the following features:

- a) monocular, either left eye or right eye,
- b) direct view, allowing all of the following modes:
    - 1) directly in front of the eye,
    - 2) look-over capability,
    - 3) look-under capability,
- a) 640x480 pixels,
- b) 26°x19° field of view,
- c) monochrome,
- d) exit pupil size: 25 mm,
- e) eye relief of 35 mm.

The helmet-mounted display shall also be capable of displaying monochromatic 640x480 pixel data from a monochrome VGA or RS-170 compatible source when operated as part of a Land Warrior IHAS system.

Light leakage around the helmet-mounted display shall be undetectable by the naked eye at ranges beyond 10 meters and undetectable with AN/PVS-5 or AN/PVS-7 night vision goggles beyond 25 meters.

The helmet-mounted display unit shall be mountable on a standard combat vehicle crew (CVC) helmet without requiring any additional holes in the helmet and using no special tools. The display shall be mountable in such a manner as to allow either left eye or right eye operation. The helmet-mounted display shall cause no interference with wearing sand, wind, and dust goggles and no interference with the storing of these goggles on top of the helmet. The helmet-mounted display shall have a stow position that causes no interference when the user is viewing other displays while inside the turret or while moving through the hatch. When the display is in the stow position it shall be turned off.

The helmet-mounted display unit shall have a cable six feet long from display electronics to the helmet, with a clip to attach to the user's clothing. The cable shall have a quick disconnect connector (QDC) between the cable clip and the display electronics that has a maximum separation force of 10 lbs. The QDC shall allow the user to egress from the vehicle in an emergency without pulling on a lanyard.

The total weight of the helmet assembly unit with helmet-mounted display, tracker sensor, one foot of intercom cable, and one foot of display cable shall weigh less than TBD pounds. The center of gravity of the helmet assembly with helmet-mounted display attached shall lie no more than TBD mm from the tragion in the front/back and side/side directions.

3.2.9 Display Control Module

The display control module shall accept real-time imagery data from the image processor and provide AMEL drive signals to the helmet-mounted display unit. It shall have the following data and control inputs and outputs:

- a) data inputs:
  - 1) monochrome 640x480 VGA input,
  - 2) RS-170 input;
- b) data outputs:
  - 1) monochrome video data to AMEL display control inputs:
- c) control inputs:
  - 1) sensor select
  - 2) brightness adjust
  - 3) contrast adjust.

3.2.10 Head Tracker Inertial Measurement Unit

The head tracker shall consist of an Intersense IS-300 head tracker with inertial measurement unit and signal processor. The inertial measurement unit shall be mounted on a standard DH-132 CVC helmet with a standard M-138/G microphone and MK-1697/G headset.

3.2.11 Head Tracker Signal Processor

The head tracker signal processor shall be an Intersense IS-300 signal processor with integral power supply.. The tracker shall have an angular accuracy of TBD radians. The tracker shall have a maximum latency of 15 milliseconds as measured from the time to make a new measurement to the time that a message containing the measurement data is received by the using electronics. The tracker shall be capable of operating in or on an armored vehicle such as a tank or infantry vehicle.

3.2.12 Commander's Control Panel

The commander's control panel shall have the following user controls:

a) sensor select (rotary switch):
   1) Visible sensor only
   2) IR sensor only
   3) Visible and IR sensors fused
   4) FLIR sensor
   5) tactical display (IVIS) (this control input shall be provided, but the tactical display interface shall not be implemented in the M113 demonstration system),
   6) UAV imagery (this control input shall be provided, but the UAV imagery interface shall not be implemented in the M113 demonstration system),
b) Panning mode select (toggle switch):
   1) Head tracker panning
   2) Joystick panning
c) Zoom mode select (toggle switch):
   1) Head tracker panning
   2) Joystick panning
d) Rear view mode select (spring loaded toggle switch):
   1) Direct view
   2) Rear view
e) Target tracker / head tracker mode (rotary push button):
   1) Target designate and track
   2) Return to head track mode
f) Slew to cue function (rotary push button):
g) Slew turret
h) Return to target tracking mode.
i) White/black hot select for IR and FLIR sensor (rotary push button):
   1) white hot
   2) black hot

The sensor/display control unit shall be mounted inside the turret in a position that allows the user to reach the controls either while standing in the hatch or while sitting in the closed turret.

3.2.13 Squad Leader's Joystick Control

A joy stick shall be provided for the squad leader to enable panning through the imagery from the panoramic staring sensor unit. The joy stick may also be used as cursor when displaying tactical display data to allow creating spot reports. (This cursor capability shall not be required in the M113 demonstration system).

3.3 System Interfaces

3.3.1 Internal System Interfaces

Internal system interfaces are shown schematically in Figure 3.1.

3.3.1.1 Sensor – Image Processor Interfaces

The system shall have two sensor – processor interfaces: 1) a gimbaled sensor video / RS-232 interface, and 2) a panoramic sensor video interface.

3.3.1.1.1 Gimbaled Sensor Video and RS-232 Interface

The gimbaled sensor shall have a video and RS-232 interface to the processor. The video interface shall consist of a 10 foot long cable assembly that carries RS-170A composite interlaced video. The RS-232 interface shall carry azimuth and elevation slewing signals to the gimbal from the processor and azimuth and elevation gimbal position signals from the gimbal to the processor.

3.3.1.1.2 Panoramic Sensor Video Interface

The panoramic sensor shall have a video interface to the processor. The video interface shall consist of a 10 foot long cable assembly that carries RS-170A interlaced composite video signals from the eight visible TV cameras to the processor. All cameras shall be synchronized by common horizontal and vertical sync signals to produce pixel-synchronous video outputs.

3.3.1.2 Sensor – Power Supply Interface

The sensor – power supply interface shall consist of two 10 foot long cable assemblies. One cable assembly shall carry power to the panoramic sensor unit. The other cable assembly shall carry power to the gimbaled sensor unit.

3.3.1.3 Sensor – RS-232 Switch Interface

The sensor – RS-232 switch interface shall consist of one 10 foot long cable assembly that carries RS-232 control signals.from the developer's control panel to the eight cameras in the panoramic sensor unit.

3.3.1.4 Image Processor – Display Interfaces

The image processor shall provide video outputs to the Honeywell Land Warrior helmet mounted display and to a standard TV monitor.

3.3.1.4.1 Image Processor – HMD Display Control Module Interface

The image processor – HMD display control module interface shall consist of a 15 foot long coaxial cable that carries a composite analog RS-170A video signal at 30 frames/sec. A second identical cable shall be provided if a second viewer; e.g., a squad leader, must be accommodated.

3.3.1.4.2 Image Processor – TV Monitor Interface

The image processor – TV monitor interface shall consist of one 15 foot long 75 ohm coaxial cable with a that carries a composite analog RS-170A video signal at 30 frames/sec.

3.3.1.5 Image Processor Control Interfaces

The image processor shall accept control inputs from the following sources:

1) head tracker
2) developer's control panel
3) commander's control panel
4) squad leader's joystick.

3.3.1.5.1 Head Tracker Signal Processor – Image Processor Interface

The head tracker signal processor – image processor interface shall consist of a 10 foot long RS-232 cable that carries angular motion data from the head tracker signal processor to the image processor.

3.3.1.5.1.1 Developer's Control Panel – Image Processor Interface

The developer's control panel – image processor interface shall consist of a 10 foot long RS-232 cable that carries image processor control commands from the developer's control panel to the image processor.

3.3.1.5.1.2 Developer's Control Panel – RS-232 Switch Interface

The developer's control panel – RS-232 switch interface shall consist of a 10 foot long RS-232 cable that carries camera control commands from the control panel to the RS-232.

3.3.1.5.1.3 Commander's Control Panel – Developer's Control Panel Interface

The commander's control panel – developer's control panel interface shall consist of a 10 foot long RS-232 cable that carries control signals from the commander's control panel to the developer's control panel (PC. It is desired that the ASCII representations for these control signals be the same as for the developer's control panel – image processor interface described in paragraph 3.3.1.5.1.1 above so that the Commander's control panel can replace the developer's control panel or PC.

3.3.1.5.1.4 Developer's Control Panel – Squad Leader's Joystick Interface

TBD

3.3.1.5.2 Commander's Control Panel – Image Processor Interface

The commander's control panel – image processor interface shall consist of a 10 foot long RS-232 cable that carries control signals from the commander's control panel to the image processor.

3.3.1.5.3 Squad Leader's Joystick – Image Processor Interface

TBD

3.3.1.6 HMD Display Control Module Interfaces

3.3.1.6.1 HMD Display Control Module – Helmet Display Interface

The helmet-mounted display control module – helmet display interface shall consist of a three foot long cable that carries video and synchronization signals to the flat panel in the helmet display assembly.

3.3.1.6.2 HMD Display Control Module – Image Processor Interface

The HMD display control module – image processor interface shall consist of a 15 foot long coaxial cable that carries a composite analog RS-170A video signal at 30 frames/sec.

3.3.1.6.3 HMD Display Control Module – FBCB2 Tactical Data Interface

The HMD display control module – FBCB2 Tactical Data Interface shall consist of a 15 foot long cable with a 15-pin connector at the FBCB2 terminal end. The FBCB2 interface shall be a standard VGA interface as found on standard personal computers

3.3.2 User Interfaces

3.3.2.1 Developer's Control Panel User Interface

The developer's control panel user interface shall consist of a standard laptop computer with keyboard and mouse.

3.3.2.2 Commander's Control Panel User Interface

The commander's control panel user interface.

3.3.2.3 Squad Leader's Joystick User Interface

TBD

3.3.2.4 HMD Display Control Module User Interface

The HMD display control module interface shall consist of the following controls:

a) video mode select switch – a five-position rotary switch that selects either:
   1) OFF
   2) the RS-170 input from the image processor,
   3) the VGA input from the FBCB2 processor,
   4) the RS-170 input from an alternate source (not used), or
   5) a TBD function (not used).
b) I^2 mode select (not used) – a three-position rotary switch that puts and external I^2 sensor in either:
   1) the OFF state,
   2) the ON state (without an illuminator), or
   3) the ON state with an illuminator ON.
c) helmet mounted display controls – three pushbuttons that operate as follows:
   1) the center pushbutton on successive depressions rotates between either BRIGHTNESS or CONTRAST adjust,
   2) the UP arrow pushbutton on successive depressions increases the brightness or contrast by one unit.
   3) the DOWN arrow pushbutton on successive depressions decreases the brightness or contrast by one unit.

The HMD display control module shall be mounted on the user (commander or squad leader) using a clip or velcro, and shall have quick-disconnect connectors for all the cables to allow unimpeded egress from the vehicle.

3.3.2.5 HMD Display User Interface

The helmet-mounted display shall having the following user interface features:

1) it shall mount on a standard DH-132 CVC helmet and liner (MIL-H-44117A), with a standard M-138/G microphone and MK-1697/G headset. No new holes shall be required in the helmet to mount the display.
2) it shall be easily removable from the helmet without tools, and shall be stowable in the vehicle as a vehicle retained unit (VRU),
3) it shall be physially and functionally compatible with a Land Warrior display having the following user interface features:
    a) monocular, either left eye or right eye,
    b) direct view, allowing all of the following modes:
        a) directly in front of the eye,
        b) look-over capability,
        c) look-under capability,
6) 640x480 pixels,
7) 26°x19° field of view,
8) monochrome,
9) exit pupil size: 25 mm,
10) eye relief: 35 mm.

The helmet-mounted display unit shall be mountable on a standard combat vehicle crew (CVC) helmet without requiring any additional holes in the helmet and using no special tools. The display shall be mountable in such a manner as to allow either left eye or right eye operation. The display shall have two positions on the helmet: an operating position and a stow position. In the stow position the display shall be turned off. In the operating position the display mount shall permit both a look over and a look under mode of operation. The display mount shall not interfere with the use of:

1) personal eyeglasses,
2) sand, wind , and dust goggles, and the storage of these goggles on the top of the helmet,
3) NBC mask,
4) head rests while using any sights inside the vehicle,
5) moving through the open hatch in either direction.

3.3.2.6 Head Tracker IMU User Interface

The head tracker inertial measurement unit shall mount on a standard DH-132 CVC helmet and liner (MIL-H-44117A), with a standard M-138/G microphone and MK-1697/G headset. No new holes shall be required in the helmet to mount the inertial measurement unit. The inertial measurement unit shall be easily removable from the helmet without tools, and shall be stowable in the vehicle as a vehicle retained unit (VRU).

3.3.2.7 FBCB2 User Interface (Optional)

The STTV system shall provide an RS-422 control interface that supplies user inputs to an

embedded tactical display or an Applique+ display for preparing reports. The RS-422 control output shall enable the HMD to provide the same capabilities that are provided by the embedded tactical display or Applique+ display:

1) display cursor control,
2) tactical display function buttons mimic'd by on-screen buttons,
3) tactical display numerical pad mimic'd by on-screen numerical pad.

This interface shall not be required in the STTV demonstration system used on an M113.

3.3.3 Vehicle Interfaces

3.3.3.1 Mechanical Interfaces

3.3.3.1.1 Sensor – Vehicle Mechanical Interface

When used on an M113 vehicle, the sensor unit (combined panoramic and gimbaled sensors) shall be mounted in the square hatch on top of the passenger compartment in back of the commander's hatch using a wooden frame constructed for this purpose. The cables shall run through the frame into the passenger compartment where the remaining system components are stowed.

When used on an M1A2 Abrams, the sensor unit shall be located on a stationary mount on top of the CITV sensor on the turret, but not in contact with the rotating turret.

3.3.3.1.2 Image Processor – Vehicle Mechanical Interface

When used on an M113 vehicle, the image processor shall be mounted in a 19 inch rack located in the passenger compartment.

3.3.3.1.3 Power Supply – Vehicle Mechanical Interface

When used on an M113 vehicle, the power supply shall be mounted in a 19 inch rack located in the passenger compartment.

3.3.3.1.4 RS-232 Switch – Vehicle Mechanical Interface

When used on an M113 vehicle, the RS-232 switch shall be mounted in a 19 inch rack located in the passenger compartment.

3.3.3.1.5 Commander's Control Panel – Vehicle Mechanical Interface

The commander's control panel shall be mounted inside the commander's hatch in a position that allows the commancer to reach the controls either while standing in the hatch or while sitting in the closed vehicle.

3.3.3.1.6 Squad Leader's Joystick – Vehicle Mechanical Interface

The squad leader's joystick shall be located in the passenger compartment of either an M113 or M2/M3 Bradley in a position where it is accesible while using the FBCB2 tactical terminal.

3.3.3.2 Electrical Interfaces

3.3.3.2.1 Power Supply – Vehicle Electrical Interface

The STTV power supply shall operate from a 110 VAC power inverter that is powered from the 28 VDC vehicle power source per MIL-STD-1275.

3.3.3.2.2 CITV – Image Processor Interface

The STTV image processor shall have a modified RS-170 input interface to accept the data from an HTI second generation FLIR used as a Commander's Independent Thermal Viewer (CITV). (This interface shall not be required in the STTV demonstration system used on an M113).

3.3.3.2.3 Developer's Control Panel - HTI FLIR Control Interface

The STTV system shall have an RS-422 control output to provide user control to a HTI second generation FLIR sensor. (This interface shall not be required in the STTV demonstration system used on an M113).

3.4 Acronyms

AMEL	Active Matrix Electroluminescent
CCD	Charge Coupled Device
CITV	Commander's Independent Thermal Viewer
CIV	Commander's Independent Viewer
CVC	Combat Vehicle Crew
FBCB2	FXXI Battle Command, Brigade and Below
FLIR	Forward Looking Infra Red
FOR	Field of Regard
FOV	Field of View
HTI	Horizontal Technology Integration
HMD	Helmet Mounted Display
Hz	Hertz
ICCD	Intensified Charge Coupled Device
IHAS	Integrated Helmet Assembly Subsystem
IVIS	Inter Vehicular Information System
NBC	Nuclear Biological Chemical

NFOV	Narrow Field of View
SVGA	Super Video Graphics Adapter
STTV	See-Through Tank Visualization
TBD	To Be Determined
UAV	Unmanned Aeronautical Vehicle
VGA	Video Graphics Adapter
WFOV	Wide Field of View

Appendix C
STTV Interface Control Document

Sensor and Guidance Products Divison

Honeywell

X	MINNEAPOLIS, MN	FSCM 94580
	ST. PETERSBURG, FL	FSCM 09128

SPECIFICATION NO. DSXXXXX-01

TYPE: [ ] SYSTEM [X] DEVELOPMENT [ ] MATERIAL [ ] ENGINEERING
[ ] PRODUCT [ ] PROCESS [ ] OTHER

TITLE: See-Through Tank Visualization System Interface Control Document

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1. SCOPE

This Interface Control Document (ICD) shall define the interfaces between the Honeywell See-Through Tank Visualization (STTV) System modules, between the STTV system and the vehicle, and between the STTV system and the user.

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent specified herein. In the event of a conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered the superseding requirement.

2.1 Government Specifications

System Requirements Specification for a See-Through Tank Visualization System, Honeywell Inc, 6 November 1998

2.2 Honeywell Specifications

System Development Specification for a See-Through Tank Visualization System, Honeywell Inc, 6 November 1998

Land Warrior IHAS Specification, Honeywell Inc, 12 January 1998

3. SYSTEM DESCRIPTION

The See Though Tank Visualization System consists of the following components as shown in Figure 3.1:

a) panoramic sensor unit
b) gimbaled IR sensor unit
c) image processor
d) power supply
e) RS-232 switch
f) developer's control panel
g) helmet assembly
h) helmet-mounted display
i) display control module
j) head tracker inertial measurement unit
k) head tracker signal processor
l) commander's control panel
m) squad leader's joystick control

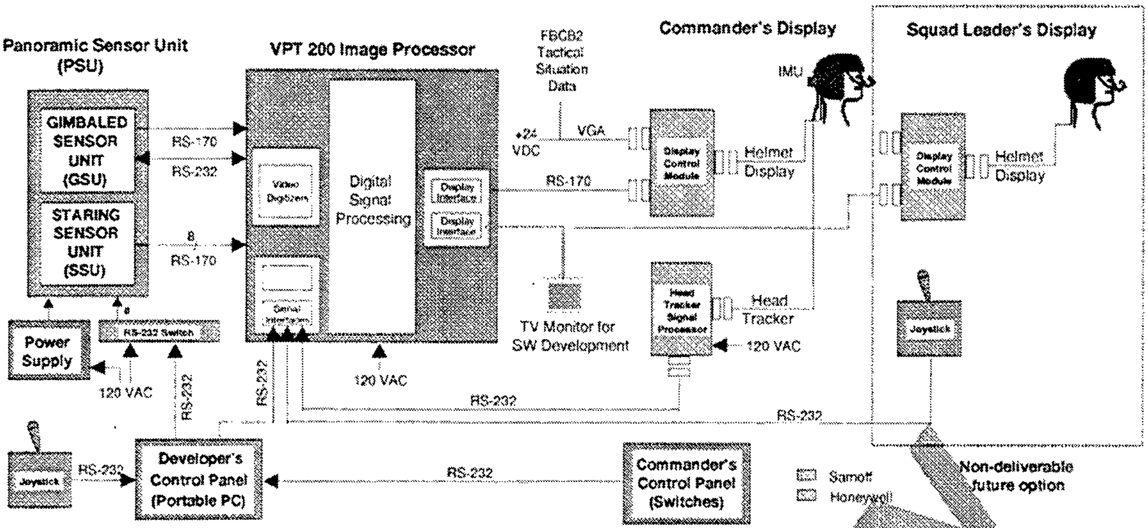

Figure 3.1 See-Through Tank Visualization System Components

4. INTERFACE REQUIREMENTS

4.1 Internal System Interfaces

Internal system interfaces are shown schematically in Figure 3.1.

4.1.1 Sensor – Image Processor Interfaces

The system shall have two sensor – processor interfaces: 1) a gimbaled sensor video / RS-232 interface, and 2) a panoramic sensor video interface.

4.1.1.1 Gimbaled Sensor Video and RS-232 Interface

The gimbaled sensor video and RS-232 interface shall consist of a 10 foot long cable assembly as shown in Appendix 1, cable P. The cable shall have a 19 pin ITT Neptune connector with three coaxial pins at the sensor end and three 75 ohm coaxial BNC connectors at the processor end along with three female DB-9 connectors and a system ON/OFF switch.

The three 75 ohm coaxial BNC connectors shall carry RS-170A composite interlaced video data from the microbolometer sensor. All three connectors shall carry the same video information. The microbolometer sensor shall have 320x240 pixels and a field of view of 15.5° (H)x11.5°(V).

One of the three female DB-9 connectors shall carry RS-232 signals and the other two shall carry RS-422 signals. Pin diagrams for these connectors are shown in Appendix 1, cable P. The RS-232 encoded signals shall carry azimuth and elevation slewing signals to the gimbal from the processor and azimuth and elevation gimbal position signals from the gimbal to the processor. The ASCII codes representing these gimbal commands and gimbal positions are listed in Appendix 2. RS-422 signals on the remaining two female DB-9 connectors are not defined at this time.

The system ON/OFF control shall consist of a single wire in the cable that is connected to an SPDT switch at the processor end. The other side of the SPDT switch is connected to the ground side of the +28 VDC supply that powers the gimbal. When the switch is closed, (i.e., the control wire grounded) the gimbal slewing motors and microbolometer sensor are all turned ON. Immediately after turn-on, the gimbal and sensor go into a self-calibration mode during which the gimbal slews to zero degrees and points down at a reference target. After calibration is complete, the gimbal slews up in elevation to a standard position. The gimbal is then ready to accept slewing commands from the processor.

4.1.1.2 Panoramic Sensor Video Interface

The panoramic sensor video interface shall consist of a 10 foot long cable assembly as shown in Appendix 1, cable H. The cable shall have a 38999 connector with eight coaxial pins at the sensor end and eight 75 ohm coaxial BNC connectors at the processor end. The eight coaxial connectors shall carry the RS-170A interlaced composite video data from the eight visible TV cameras in the panoramic sensor assembly to the processor. Each camera shall have a field of view of 45°(H)x42°(V) with approximately 512 pixels in the horizontal direction by 494 pixels in the vertical direction. (The camera actually has 659x494 pixels distributed over a lens FOV of 58°(H)x42°(V), but only the middle 45° in the horizontal direction is used). All the pixels in both the odd and even RS-170A fields are illuminated simultaneously. Scan converters in the sensor assembly re-format the field-parallel outputs of each camera into standard field-sequential RS-170A signals to the processor. All cameras are synchronized by the same horizontal and vertical TTL sync signals, producing pixel-synchronus video output. The processor is synchronized using the composite sync included in the RS-170A interlaced outputs.

4.1.2 Sensor – Power Supply Interface

The sensor – power supply interface shall consist of two 10 foot long cable assemblies, cable WIK (three diagrams in one cable) and S (a separate cable), as shown in Appendix 1 cables W, K, and S.

Cable WIK shall have a 51-pin 38999 connector at one end and multiple U-shaped terminals at the other end. Sub-cable W of cable WIK shall carry +5 VDC power to the panoramic sensor unit. It shall have eight +5 VDC power terminals and eight +5 VDC return (ground) terminals at the power supply end. Sub-cable K of cable WIK shall carry +12 VDC power to the panoramic sensor unit. It shall have five +12 VDC power terminals and eight +12 VDC return (ground) terminals at the power supply end.

Cable S shall have a 19-pin ITT Neptune connector at the sensor end and multiple U-shaped terminals at the power supply end. It shall carry +24 VDC power to the gimbaled sensor unit. Cable S shall have nine +24 VDC power terminals and nine +24 VDC return (ground) terminals at the power supply end.

4.1.3 Sensor – RS-232 Switch Interface

The sensor – RS-232 switch interface shall consist of one 10 foot long cable assembly, subcable I of cable WIK, as shown in Appendix 1, cable I. The cable shall have a 51-pin 38999 connnector at one end and eight DB-25 male connectors at the other end. Pin diagrams for the DB-25 connectors are shown in Appendix 1, cable I. The cable shall carry RS-232 control signals from the developer's control panel to the eight cameras in the panoramic sensor unit. The RS-232 encoded signals shall permit changing the camera integration time, gain, and output modes. The ASCII codes representing these camera modes are listed in Appendix 3.

4.1.4 Image Processor – Display Interfaces

The image processor shall provide video outputs to the Honeywell Land Warrior helmet mounted display and to a standard TV monitor.

4.1.4.1 Image Processor – HMD Display Control Module Interface

The image processor – HMD display control module interface shall consist of a 15 foot long 75 ohm coaxial cable with a 75 ohm BNC connector at the image processor end and a male 8 pin Lemo connector at HMD display control module end. A cable pin diagram is shown in Appendix 4. The cable shall carry a composite analog RS-170A video signal at 30 frames/xec. If the system must accommodate a second viewer; e.g., a squad leader in addition to a commander, then a second identical cable shall be provided.

4.1.4.2 Image Processor – TV Monitor Interface

The image processor – TV monitor interface shall consist of one 15 foot long 75 ohm coaxial cable with a 75 ohm BNC connector at each end. The cable shall carry a composite analog RS-170A video signal at 30 frames/xec.

4.1.5 Image Processor Control Interfaces

The image processor shall accept control inputs from the following sources:

1) Intersense head tracker
2) developer's control panel
3) commander's control panel
4) squad leader's joystick.

4.1.6 Head Tracker Signal Processor – Image Processor Interface

The head tracker signal processor – image processor interface shall consist of a 10 foot long RS-232 cable with a DB-9 connector at the tracker signal processor end and either a DB-25 connector at the image processor. The cable shall be configured as a null modem cable as shown in Table 1; i.e.. with the TX at each end connected to the RX at the other end, and the grounds at each end connected together. The cable shall carry angular motion data from the head tracker signal processor to the image processor at a selectable baud rate of 9,600 to 115.200 bps. The PC commands used to operate the tracker and are listed in Appendix 5.

Table 1. Head tracker cable wiring diagram

Intersense Port DB-9 Pin / Signal	Processor Port DB-9 Pin / Signal	Processor Port DB-25 Pin / Signal
1 (DCD)		
2 (RX)	3 (TX)	3 (TX)
3 (TX)	2 (RX)	2 (RX)
4 (DTR)		
5 (GND)	5 (GND)	7 (GND)
6 (DSR)		
7 (RTS)		
8 (CTS)		
9 (RI)		

4.1.6.1 Developer's Control Panel – Image Processor Interface

The developer's control panel – image processor interface shall consist of a 10 foot long RS-232 cable with a female DB-9 connector at the control panel (PC) end and a male DB-25 connector at the image processor end. The cable shall be configured as a null modem cable as shown in Table 1; i.e., with the TX at each end connected to the RX at the other end, and the grounds at each end connected together. The cable shall carry image processor control commands from the developer's control panel to the image processor at a selectable baud rate of 9,600 to 115,200 bps. The PC commands used to control the image processor are listed in Appendix 6.

4.1.6.1.1 Developer's Control Panel – RS-232 Switch Interface

The developer's control panel – RS-232 switch interface shall consist of a 10 foot long RS-232 cable with a female DB-9 connector at the control panel (PC) end and a male DB-25 connector at the RS-232 switch end. The cable shall be configured as a null modem cable as shown in Table 1; i.e.. with the TX at each end connected to the RX at the other end, and the grounds at each end connected together --- **ask Sarnoff if this is correct).** The cable shall carry camera control commands from the control panel to the RS-232 switch at a selectable baud rate of 75 to 19,200 bps. The ASCII commands used to control the RS-232 switch are listed in Appendix 7.

4.1.6.1.2 Commander's Control Panel – Developer's Control Panel Interface

The commander's control panel – developer's control panel interface shall consist of a 10 foot long RS-232 cable with a female DB-9 connector at the commander's control panel end and a female DB-9 connector at the developer's control panel (PC) end. The cable shall be configured as a null modem cable as shown in Table 1; i.e., with the TX signal at each end connected to the RX signal at the other end, and the grounds at each end connected together. The cable shall carry control signals from the commander's control panel to the developer's control panel (PC) at a selectable baud rate of 9,600 to 115,200 bps. The control signals and their ASCII representations are listed in Appendix 9. It is desired that the ASCII representations for these control signals be the same as for the developer's control panel – image processor interface described in paragraph 4.1.6.1 above so that the Commander's control panel can replace the developer's control panel or PC. **NOTE**: When this replacement is done, the interface is described in paragraph 4.1.6.1.3 below.

4.1.6.1.3 Developer's Control Panel – Squad Leader's Joystick Interface

TBD

4.1.6.2 Commander's Control Panel – Image Processor Interface

The commander's control panel – image processor interface shall consist of a 10 foot long RS-232 cable with a female DB-9 connector at the commander's control panel end and a female DB-25 connector at the image processor end. The cable shall be configured as a null modem cable as shown in Table 1; i.e., with the TX signal at each end connected to the RX signal at the other end, and the grounds at each end connected together. The cable shall carry control signals from the commander's control panel to the image processor at a selectable baud rate of 9,600 to 115,200 bps. The control signals and their ASCII representations are listed in Appendix 9.

4.1.6.3 Squad Leader's Joystick – Image Processor Interface

TBD

4.1.7 HMD Display Control Module Interfaces

4.1.7.1 HMD Display Control Module – Helmet Display Interface

The helmet-mounted display control module – helmet display interface shall consist of a three foot long cable with a male 30 pin Lemo connector at the display control module end and a male 30 pin Omnetics connector at the helmet display end. The cable diagram is shown in Appendix 6.1, cable X.

4.1.7.2 HMD Display Control Module – Image Processor Interface

The HMD display control module – image processor interface shall consist of a 15 foot long 75 ohm coaxial cable with a 75 ohm BNC connector at the image processor end and a male 8 pin Lemo connector at HMD display control module end. A cable diagram is shown in Appendix 4. The cable shall carry a composite analog RS-170A video signal at 30 frames/xec. If the system must accommodate a second viewer; e.g., a squad leader in addition to a commander, then a second identical cable shall be provided.

4.1.7.3 HMD Display Control Module – FBCB2 Tactical Data Interface

The HMD display control module – FBCB2 Tactical Data Interface shall consist of a 15 foot long cable with a female 19-pin Lemo connector at the HMD display control module end and a female 15-pin HDB-15 connector at the FBCB2 terminal end. The FBCB2 interface shall be a standard VGA interface as found on standard personal computers, and shall have the pinout as shown in Table 2. The end with the 15 pin connector shall have an additional stub 10 feet long that contains four additional wires, including a +24 VDC power and ground for supplying the DCM with power.

Table 2. Contact diagram for VGA interface (female DB-9 connector)

Socket Number	Signal
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	

4.2 User Interfaces

4.2.1 Developer's Control Panel User Interface

The developer's control panel user interface shall consist of a standard Dell laptop computer (or equivalent) with keyboard and mouse (or equivalent).

4.2.2 Commander's Control Panel User Interface

The commander's control panel user interface is shown in Appendix 9, Figure 1. The STTV system modes of operation controlled via this interface shall be as described in Appendix 10, Table 1.

4.2.3 Squad Leader's Joystick User Interface

TBD

4.2.4 HMD Display Control Module User Interface

The HMD display control module interface shall consist of the following controls:

1) video mode select switch – a five-position rotary switch that selects either:
    a) OFF
    b) the RS-170 input from the image processor,
    c) the VGA input from the FBCB2 processor,
    d) the RS-170 input from an alternate source (not used), or
    e) a TBD function (not used).

2) I^2 mode select (not used) – a three-position rotary switch that puts an external I^2 sensor in either:
   a) the OFF state,
   b) the ON state (without an illuminator), or
   c) the ON state with an illuminator ON.
3) helmet mounted display controls – three pushbuttons that operate as follows:
   a) the center pushbutton on successive depressions rotates between either BRIGHTNESS or CONTRAST adjust,
   b) the UP arrow pushbutton on successive depressions increases the brightness or contrast by one unit,
   c) the DOWN arrow pushbutton on successive depressions decreases the brightness or contrast by one unit.

The HMD display control module shall be mounted on the user (commander or squad leader) using a clip or velcro, and shall have quick-disconnect connectors for all the cables to allow unimpeded egress from the vehicle.

4.2.5 HMD Display User Interface

The helmet-mounted display shall having the following user interface features:

a) it shall mount on a standard DH-132 CVC helmet and liner (MIL-H-44117A), with a standard M-138/G microphone and MK-1697/G headset. No new holes shall be required in the helmet to mount the display,
b) it shall be easily removable from the helmet without tools, and shall be stowable in the vehicle as a vehicle retained unit (VRU),
c) it shall be physically and functionally compatible with a Land Warrior display having the following user interface features:
d) monocular, either left eye or right eye,
e) direct view, allowing all of the following modes:
f) directly in front of the eye,
g) look-over capability,
h) look-under capability,
i) 640x480 pixels,
j) 26°x19° field of view,
k) monochrome,
l) exit pupil size: 25 mm,
m) eye relief: 35 mm.

The helmet-mounted display unit shall be mountable on a standard combat vehicle crew (CVC) helmet without requiring any additional holes in the helmet and using no special tools. The display shall be mountable in such a manner as to allow either left eye or right eye operation. The display shall have two positions on the helmet: an operating position and a stow position. In the stow position the display shall be turned off. In the operating position the display mount shall permit both a look over and a look under mode of operation. The display mount shall not interfere with the use of:

a) personal eyeglasses,
b) sand, wind , and dust goggles, and the storage of these goggles on the top of the helmet,

c) NBC mask,
d) head rests while using any sights inside the vehicle,
e) moving through the open hatch in either direction.

4.2.6 Head Tracker IMU User Interface

The head tracker inertial measurement unit shall mount on a standard DH-132 CVC helmet and liner (MIL-H-44117A), with a standard M-138/G microphone and MK-1697/G headset. No new holes shall be required in the helmet to mount the inertial measurement unit. The inertial measurement unit shall be easily removable from the helmet without tools, and shall be stowable in the vehicle as a vehicle retained unit (VRU).

4.2.7 FBCB2 User Interface (Optional)

The STTV system shall provide an RS-422 control interface to provide user inputs to an embedded tactical display or an Applique+ display for preparing reports. A TBD type connector shall be employed. The RS-422 control output shall provide the following capabilities to the HMD that are provided by the embedded tactical display or Applique+ display.:

1) display cursor control,
2) tactical display function buttons mimic'd by on-screen buttons,
3) tactical display numerical pad mimic'd by on-screen numerical pad.

This interface shall not be required in the STTV demonstration system used on an M113.

4.3 Vehicle Interfaces

4.3.1 Mechanical Interfaces

4.3.1.1 Sensor – Vehicle Mechanical Interface

When used on an M113 vehicle, the sensor unit (combined panoramic and gimbaled sensors) shall be mounted in the square hatch on top of the passenger compartment in back of the commander's hatch using a wooden frame constructed for this purpose. The cables shall run through the frame into the passenger compartment where the remaining system components are stowed.

When used on an M1A2 Abrams, the sensor unit shall be located on a stationary mount on top of the CITV sensor on the turret, but not in contact with the rotating turret.

4.3.1.2 Image Processor – Vehicle Mechanical Interface

When used on an M113 vehicle, the image processor shall be mounted in a 19 inch rack located in the passenger compartment.

4.3.1.3 Power Supply – Vehicle Mechanical Interface

When used on an M113 vehicle, the power supply shall be mounted in a 19 inch rack located in the passenger compartment.

4.3.1.4 RS-232 Switch – Vehicle Mechanical Interface

When used on an M113 vehicle, the RS-232 switch shall be mounted in a 19 inch rack located in the passenger compartment.

4.3.1.5 Commander's Control Panel – Vehicle Mechanical Interface

The commander's control panel shall be mounted inside the commander's hatch in a position that allows the commander to reach the controls either while standing in the hatch or while sitting in the closed vehicle.

4.3.1.6 Squad Leader's Joystick – Vehicle Mechanical Interface

The squad leader's joystick shall be located in the passenger compartment of either an M113 or M2/M3 Bradley in a position where it is accessible while using the FBCB2 tactical terminal.

4.3.2 Electrical Interfaces

4.3.2.1 Power Supply – Vehicle Electrical Interface

The STTV power supply shall operate from a 110 VAC power inverter that is powered from the 28 VDC vehicle power source per MIL-STD-1275. (Note: This requires the 110 VAC inverter to operate over the input range of 16VDC to 30 VDC).

5. ACRONYMS

AMEL	Active Matrix Electroluminescent
CCD	Charge Coupled Device
CITV	Commander's Independent Thermal Viewer
CIV	Commander's Independent Viewer
CVC	Combat Vehicle Crew
FBCB2	FXXI Battle Command, Brigade and Below
FLIR	Forward Looking Infra Red
FOR	Field of Regard
FOV	Field of View
HTI	Horizontal Technology Integration
HMD	Helmet Mounted Display
Hz	Hertz
ICCD	Intensified Charge Coupled Device
IHAS	Integrated Helmet Assembly Subsystem
IVIS	Inter Vehicular Information System
NBC	Nuclear Biological Chemical
NFOV	Narrow Field of View
SVGA	Super Video Graphics Adapter
STTV	See-Through Tank Visualization
TBD	To Be Determined
UAV	Unmanned Aeronautical Vehicle
VGA	Video Graphics Adapter
WFOV	Wide Field of View

6. APPENDICES

6.1 Cable Diagrams
6.2 Gimbal Commands
6.3 Camera Commands
6.4 Image Processor – HMD Display Video Cable Diagram
6.5 PC Commands to Head Tracker
6.6 PC Commands to Control Image Processor
6.7 ASCII Commands and Settings for RS-232 Switch Operation
6.8 ASCII Representations of Control Modes for Commander's Control Panel
6.9 Commander's Control Panel Controls and Modes of Operation

Appendix D
SPIE Paper

Combat vehicle visualization system

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ABSTRACT

A combat vehicle visualization system is described that enhances the situation awareness of the vehicle commander. The system consists of a 360° panoramic sensor, a gimbaled 8-12 μm infrared sensor, and a helmet-mounted display with head tracker. The helmet-mounted display can display the fused sensor data to aid the commander in vehicle maneuvering and threat acquisition while buttoned up. It can also display situation awareness information down-loaded from the tactical internet while standing in the hatch. Construction and operation features will be described.

Keywords: Helmet mounted display, HMD, situation awareness, visualization, panoramic camera, image processing, M1A2

1. INTRODUCTION

As a result of lessons learned in Operation Desert Storm, the U.S. Army is adding to its armored vehicles a selection of electronic systems to enhance their lethality and survivability (Table 1). These systems give drivers and gunners improved tools for performing existing tasks, while they give commanders exciting new capabilities as well as new demands on their heavy workload. The commander's independent thermal viewer on the M1A2 Abrams, for example, allows the commander to hunt for new targets while the gunner is dispatching an existing target, a capability that was not present on the M1A1. While this provides up to a 60% improvement in the effective rate of fire[1], the commander's attention may be diverted from other essential tasks such as vehicle navigation and vehicle communication.

Table 1. New and improved electronics for Army vehicles

Electronic System	Description	Use
GPS Navigation System[2]	Precision lightweight GPS receiver (PLGR)	Cmdr & driver navigation
Driver's Vision Enhancer[3,4]	8-12 micron uncooled infrared sensor	Driver terrain viewing
Gunner's Primary Sight[5]	8-12 micron 2nd generation FLIR sensor	Gunner target sighting
Battlefield Combat ID System[6,7]	Ka-band narrow beam interrogator plus omni-directional receiver / transponder	Gunner friend/foe identification
Commander's Independent Viewer[8]	8-12 micron 2nd generation FLIR sensor	Cmdr target hunting
FBCB2 Tactical Terminal[9,10]	Networked Appliqué or embedded computer	Cmdr situation awareness

The most demanding new system for vehicle commanders is the FXXI Battle Command Brigade and Below (FBCB2) tactical terminal. This networked computer system provides increased situation awareness in the form of rapid accessibility to enemy and friendly positions, topographical maps, commander's orders, situation reporting, and vehicle needs/status reporting. The situation awareness data allows the commander to make more informed and rapid decisions locally prior to and during an enemy encounter. But interaction with the digital terminal adds to the commander's workload.

The commander's workload is stressed the most in the case of turreted armored vehicles such as the Abrams and the Bradley. When not engaging the enemy, the vehicle commander is trained to stand in the hatch while the vehicle is moving and to search continuously for road hazards, ground-based threats, friendly forces, and other objects or situations that might affect his vehicle. He is constantly giving verbal commands over the vehicle's intercom system to tell the driver to turn right or left or the gunner to slew the turret right or left. While standing in the hatch he is unable to use the commander's independent thermal viewer

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(CITV) or the FBCB2 tactical terminal because their displays are viewable only while inside the turret. This makes it difficult to prepare situation reports while maintaining outside awareness. It may even cause him to miss a critical communication from his commander.

When engaging the enemy and the vehicle is buttoned up, the situation is reversed. In this case, the CITV display and the FBCB2 tactical terminal are directly viewable, but the commander has no awareness of the vehicle's immediate surroundings or its turret-hull orientation. The commander's independent thermal viewer is excellent for acquiring targets at longer ranges, but its narrow field of view (13.3°x7.5° maximum) and limited slew rate (60°/sec) are not well matched to seeing threats at nearby ranges (≤ 400 meters). The commander's viewing ports are intended to provide such a capability, but they are limited to visible light only and are frequently taped over to preclude the enemy from spotting the vehicle due to light emanating through the ports.

With these needs in mind, Honeywell and the Sarnoff Corporation have contracted with DARPA to develop the See-Through Turret Visualization (STTV) system (Figure 1). The STTV system provides the vehicle commander a 360° field of view panoramic image sensor along with a helmet mounted display and head tracker. When not engaging the enemy, the helmet-mounted display allows the commander to view the FBCB2 terminal data while standing in the hatch. When engaging the enemy, the panoramic sensor allows the commander effectively to see through the vehicle's armor and to view the surrounding terrain on his helmet-mounted display. Panning around the vehicle is achieved naturally via the head-tracked sensor, leaving hands free for other duties. On a troop-carrying armored vehicle, such as a Bradley, the panoramic sensor enables an additional optional mode whereby the squad leader can survey the surrounding terrain before disembarking on a mission. In this mode the squad leader can pan the panoramic sensor independently of the vehicle commander, allowing the commander and squad leader to look simultaneously in different directions.

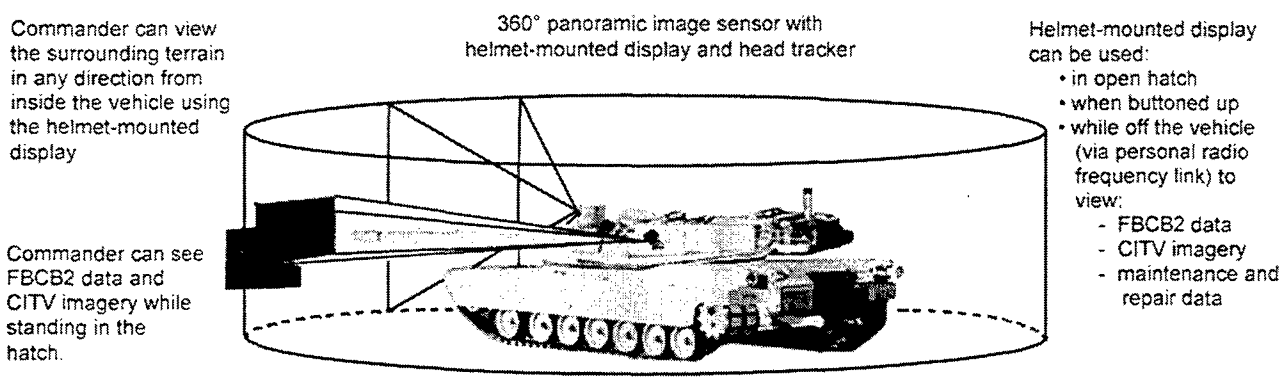

Figure 1. See-Through Turret Visualization system

2. STTV SYSTEM DESCRIPTION

The following sections describe a prototype See-Through Turret Visualization (STTV) system developed using existing components to demonstrate essential system features in a cost-effective manner. Improvements envisioned for a deployable production system are addressed in Section 3.

2.1. 360° Panoramic Sensor

The 360° panoramic sensor (Figure 2) consists of eight 659x494 pixel visible charge-coupled device (CCD) cameras with each camera having a 6 mm auto iris lens with a field of view of 56°(H)x42°(V). A mirror arrangement allows the camera-to-mirror distance to be adjusted so that the cameras can be brought to a common virtual focal point, eliminating any parallax between the cameras. This assures that any objects in between two cameras are not doubly imaged or omitted, which can occur if camera vergence is not changed with distance as it is with human eyes. Actually, the camera-to-mirror distance is adjusted so that adjacent cameras have slightly overlapping horizontal fields of view to simplify the blending at image borders. This leaves a residual parallax due to a virtual camera separation of about ¼ to ½ inch, which is imperceptible at ranges beyond about 15 feet. A processor is then used to blend adjacent images into a combined intermediate camera view, enabling continuous panning through 360° as though one is looking at a single 360° panoramic image.

Another important sensor feature is that motion blur caused by image offset between two fields of the same frame is completely eliminated[11,12]. The cameras also have an RS-232 interface that allows the processor to change the camera integration time and gain settings in real time.

The complete panoramic sensor is 14 inches in diameter by 23 inches high, which allows it to be placed on top of an armored vehicle and still see the ground 15 feet away. Alternatively, only the 13 inch high camera portion can be located outside the vehicle with the 10 inch high electronics portion placed inside. The sensor has a transparent acrylic window to keep out dust and moisture.

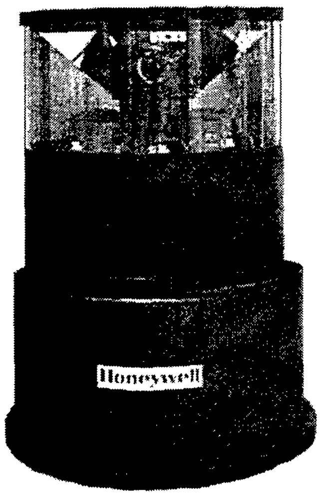

Figure 2. STTV panoramic image sensor

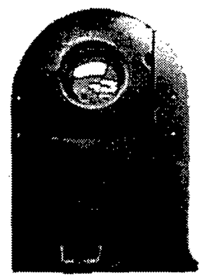

Figure 3. STTV gimbaled infrared sensor

2.2. Gimbaled Infrared Sensor

The gimbaled infrared (IR) sensor (Figure 3) is a commercially available unit developed by Nytech Inc. for the United States Army[13]. The sensor has an RS-170 video output and an NETD of less than 0.100K. It is gimbal-mounted so that can be slewed in both the azimuth and elevation directions. The azimuth gimbal is capable of continuous rotation. Its absolute pointing accuracy is one part in 4096, or 5 minutes of accuracy. The unit accepts position and velocity commands via an RS-232 interface and provides feedback of its intermediate gimbal positions while slewing. The complete unit is 14 inches high and 10 inches in diameter. It dissipates 20 watts at idle and up to 200 watts at maximum acceleration. In the STTV system this sensor is used to simulate the commander's forward-looking infrared (FLIR) sensor found on many armored vehicles, such as the CITV on the M1A2 Abrams or the Commander's Independent Viewer (CIV) on the M2A3 Bradley. If the vehicle already has a commander's FLIR onboard, this sensor can be omitted. Otherwise, it provides a low cost alternative to a high performance FLIR sensor.

The gimbaled infrared sensor can be mounted atop the 360° panoramic sensor to provide a merged sensor (Figure 4). The sensors can be used either singly or together in a fused mode as shown in Figure 5. When viewed on a helmet-mounted display, only a portion of the 360° field of view is displayed at one time. This portion is adjusted to be equal to the angular sub-tense of the display in front of the eye in order to make the scale factor of the displayed image equal to that of the real world. This makes the panning rate of the imagery in the display equal to the rate of head motion, which minimizes user discomfort. An electronic zoom capability is also provided.

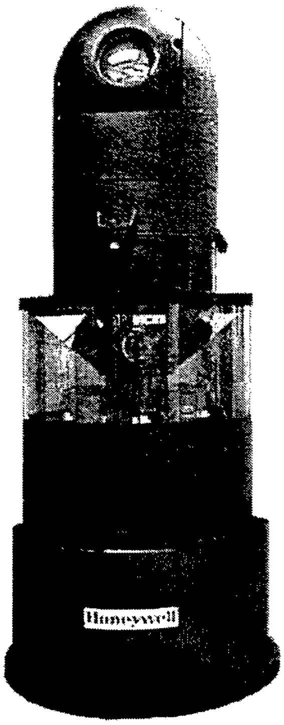

Figure 4. Combined sensors

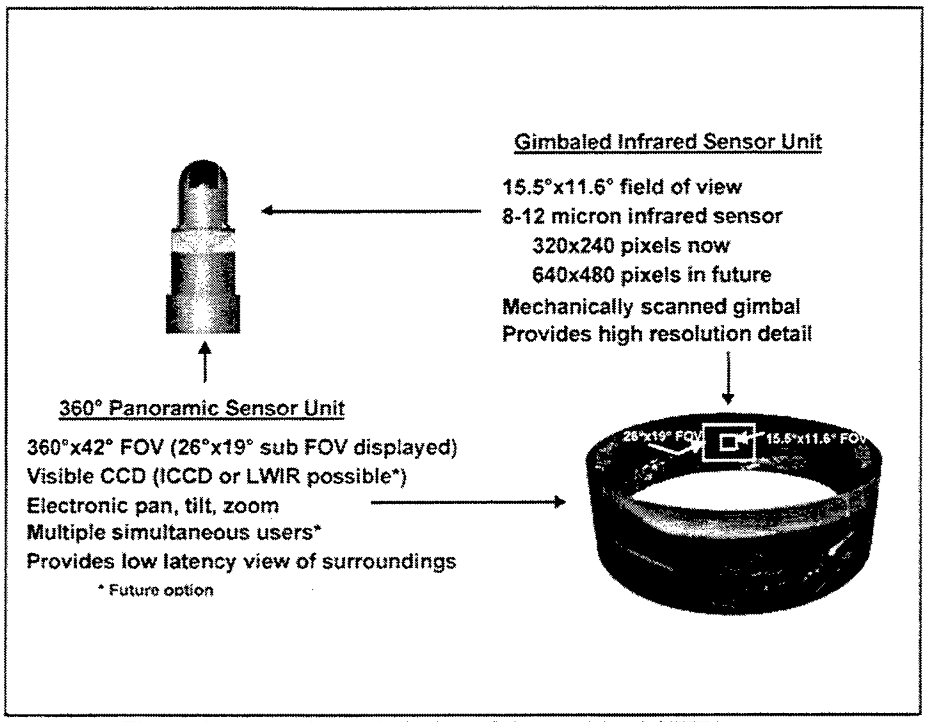

Figure 5. Operation and display of the combined STTV sensors

2.3. Helmet-Mounted Display with Head Tracker

The prototype STTV helmet-mounted display (Figure 6) is a 640x480 pixel monochrome AMEL display with a field of view of 26°(H)x19°(V). It is mounted on a standard Combat Vehicle Crew (CVC) helmet in a way that allows convenient viewing while minimizing interference when moving through the hatch or using an optical sight. The display mount has four detent positions: 1) a viewing position directly in front of the eye, 2) a viewing position seven degrees below the line of sight that allows looking over the display, 3) a stow position beside the user's chin, and 4) a stow position behind the user's right ear. The mount allows adjustment of the display-to-eye distance, the inter-pupillary distance, and the horizontal detent position. The display has brightness and contrast controls and can be switched to display either STTV video or FBCB2 situation data. The same helmet mount can accommodate an 800x600 color display that provides improved intelligibility of the FBCB2 data.

The prototype STTV head tracker is a commercially available IS-300 head tracker made by InterSense Inc.[14]. It has an angular accuracy of 1° to 3° RMS and an update rate of 150 Hz. Its 1.1x1.2x1.3 inch inertial measurement unit is attached atop the CVC helmet and provides three degrees of freedom via an RS-232 data link. The inertial measurement unit uses inexpensive angular rate gyros that provide acceptable performance in a laboratory environment. However, the update technique used to correct for gyro drift, based on sensing the earth's gravitational and magnetic fields during periods of head motion inactivity, is not intended for use on a moving armored vehicle. When operation on a moving armored vehicle is desired, Honeywell's metal-tolerant magnetic tracker can be used. This tracker has been tested on an M113 armored personnel carrier, and has been confirmed to operate with the accuracy needed by the STTV display system.

2.4. Image Processor

The STTV image processor (Figure 7) is a PVT-200 processor developed by the Sarnoff Corporation under previous DARPA contracts[15]. It is sold commercially by Pyramid Vision Technologies[16]. It consists of an 8-slot 6Ux160 subrack in a

14x19x11 inch enclosure. The eight slots are populated with a processor motherboard (two slots) and six video processor motherboards. The processor motherboard contains two C40 digital signal processors (DSP's) and two daughter boards, with each daughter board providing another C40 DSP. All four DSP's have 5 Mbytes of fast static RAM each. Each video processor motherboard contains four 2 Mbyte and one 16 Mbyte simultaneous read/write frame store memories, four pyramid processors, and two reconfigurable processing elements, plus two video processor daughter boards. Each video processor daughter board performs a special-purpose video processing function such as warping, correlation, digitization of analog video, or displaying digital output in an analog format. The arrangement of video processor daughter boards is reconfigurable, and in the case of the STTV system consists of three digitizer boards for nine video channels, six warper boards for image transformations, one correlator board for three channels of image correlation, and two display boards. Video processing is accomplished by pipelining an image from a video frame store or DSP memory, routing it through one or more reconfigurable processing elements, daughter boards, or DSP's, and writing it back into a video frame store or DSP. Multiple video frames are processed simultaneously using high bandwidth programmable interconnections between the video memories and processing elements. Each motherboard has a crosspoint switch with a 1.2 Gbytes/sec bandwidth that routes its eight video input busses (33 Mbytes/sec each) to its various onboard processing elements and then routes their results to its eight video output busses. The motherboards, in turn, communicate with each other via a second crosspoint switch of 1.8 Gbytes/sec bandwidth that comprises the global backplane bus. This architecture allows multiple frames of video to be processed concurrently, yielding an equivalent processor throughput of 50 Giga-operations per second. The processor has nine RS-170 composite analog inputs, two RS-170 composite analog outputs, and four RS-232 control ports.

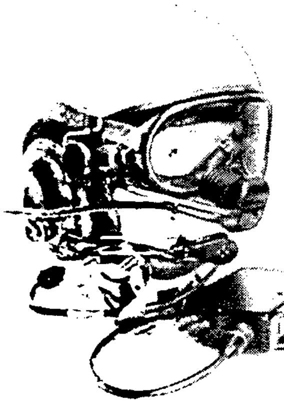

Figure 6. STTV helmet-mounted display

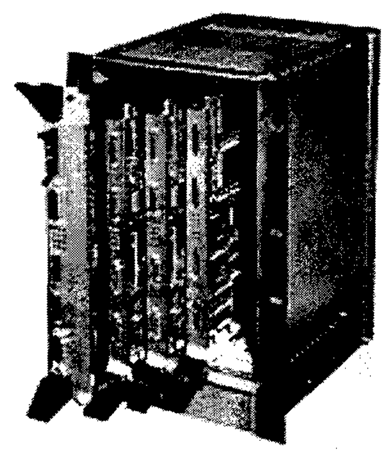

Figure 7. STTV image processor

The PVT-200 processor performs all of the image processing and control functions in the STTV system. It digitizes the outputs of the eight panoramic sensor cameras, selecting the one or two video data streams that contain the commander's current field of view, and warping the images to correct for lens distortion. The processor then warps the adjacent images again in real time to synthesize two new sub-images in the correct line of sight direction, stitching them together and blending them to make a continuous image without any noticeable joints or seams. In the meantime, it slews the IR sensor to the same line of sight position and digitizes the IR camera output, displaying it either separately or fused with the visible sensor data. Electronic zoom is also applied. Finally, a moving object tracker is provided that enables the visible and IR sensors to remain locked onto a designated target while the vehicle and the user's head undergo arbitrary motion. Image stabilization can also be provided electronically via the PVT-200. The algorithms for these functions were adapted from algorithms developed by the Sarnoff Corporation under previous DARPA contracts[17,18,19].

2.5. Commander's Control Panel

The STTV system is controlled via the commander's control panel shown in Figure 8. The commander can choose to display the visible panoramic sensor only, the gimbaled IR sensor only, or both sensors together in a fused mode. A fourth selection enables the display of a second-generation FLIR sensor with appropriate warping of the imagery to show it on a display having square pixels. The IR imagery or FLIR imagery can be viewed as either white hot or black hot to allow for thermal

inversion depending on the time of day. Viewing is done in response to the user's head orientation, which can pan through a full 360° of azimuth, 180° of azimuth, and 360° of head roll. By holding down the HMD VIEW toggle switch, the user can see a rear view 180° in back of his head while avoiding the need to turn his head 180°. When viewing imagery, the user can zoom either in or out or can make the size of the target reticle larger or smaller. These functions allow one to select an object in the current field of view, which can then be tracked by pressing the DESIGNATE & TRACK TARGET pushbutton. While the selected object is being tracked in a special tracking window by the visible and IR sensors, the user can continue to

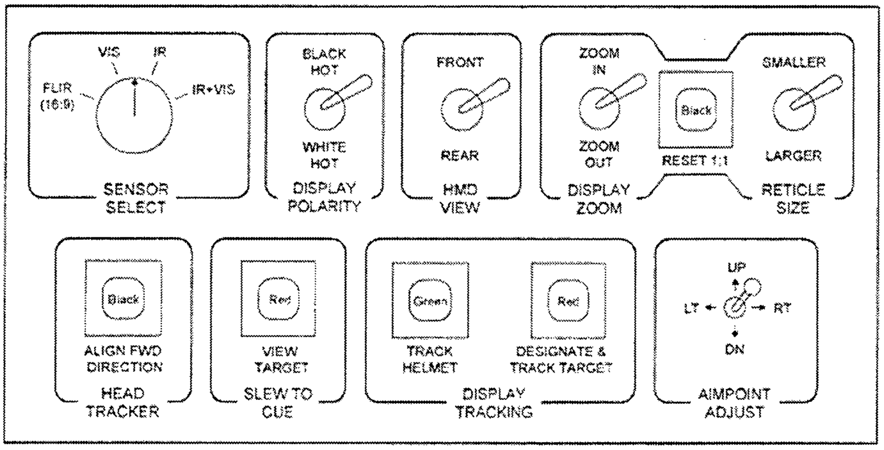

Figure 8. Commander's control panel

pan the visible panoramic sensor in an arbitrary direction in the original window. As the target object slides off the edge of the field of view, an indicator arrow appears to show the user in which direction he should turn his head to re-acquire the tracked object. The user can view the target in the tracking window at any time by depressing the VIEW TARGET pushbutton. This function simulates the slew-to-cue function found on the M1A2 Abrams and the M2A3 Bradley. While pressing the VIEW TARGET pushbutton the user can re-center the tracking window on a smaller sub-object in the tracked object and then select that sub-object by using the DISPLAY ZOOM, RETICLE SIZE, and AIMPOINT ADJUST switches. Pressing the DESIGNATE & TRACK TARGET pushbutton a second time then causes only the smaller sub-object to be tracked. Releasing the VIEW TARGET pushbutton returns the display to the original window in the direction indicated by the user's head position, but with the target still being tracked in the unseen tracking window. When the user wishes to exit the target tracking mode he depresses the TRACK HELMET pushbutton, which returns control of the visible and IR sensors to the head tracker in the current head position. The remaining ALIGN FWD DIRECTION switch is used to align the head tracker to the forward-facing sensor direction, defined to be the front of the vehicle's turret. The user depresses this pushbutton while pointing his head forward in the turret as indicated by aligning a crosshair on the display with a mark on the turret's front wall. Alignment only needs to be performed once on system power-up.

2.6. System Block Diagram

A block diagram of the complete STTV system is shown in Figure 9. The PVT-200 processor accepts imagery from the visible and IR sensors and generates RS-170 outputs for the vehicle commander's helmet-mounted display and an optional squad leader's helmet-mounted display. The commander controls both the visible and IR sensors via the commander's control panel and pans through the selected imagery using his on-helmet tracker. In a future option, the squad leader will have access to the imagery from the visible panoramic sensor, with a vehicle-mounted joystick for panning. The squad leader will then be able to pan and view the visible panoramic sensor in any direction independently of the vehicle commander while the vehicle commander is using the same sensor for other purposes. Both the vehicle commander and the squad leader will have access to the FBCB2 tactical situation data on their helmet-mounted displays.

The prototype STTV system uses a laptop computer as a control panel for development purposes to facilitate system changes and to aid in software development. In a deployable STTV system the laptop computer will not be used and the commander's control panel will communicate directly with a ruggedized version of the PVT-200 processor.

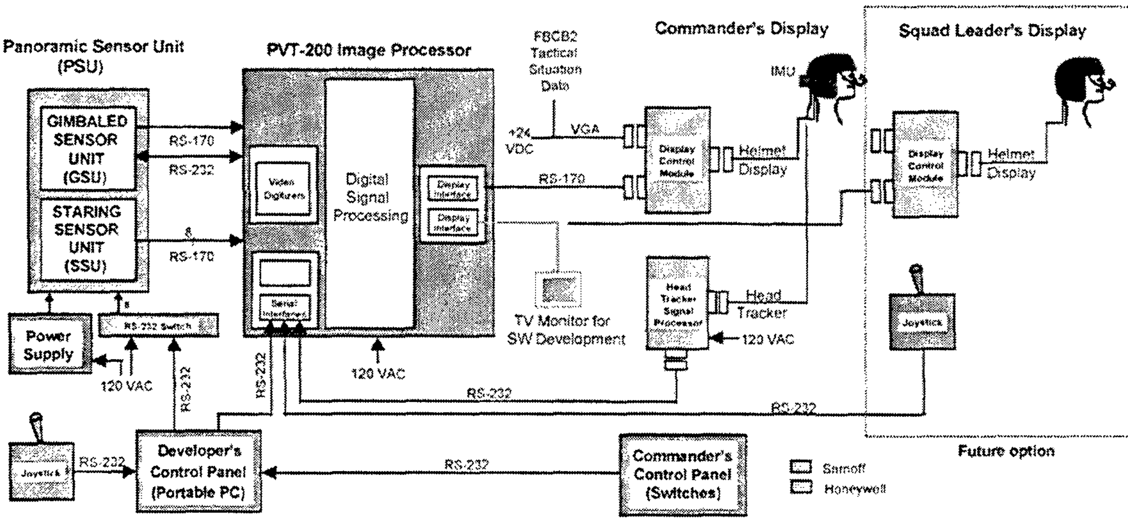

Figure 9. STTV system block diagram

3. DEPLOYABLE STTV SYSTEM FEATURES

The prototype STTV system is useful for demonstrating system operation. but does not address all the system requirements because it uses only existing components to reduce development cost. A deployable STTV system will use improved components that are better matched to the system requirements. It will also have additional image processing functions and more complete integration into the vehicle systems. Table 2 shows some of the improvements envisioned in a deployable STTV system.

One major improvement is upgrading the 360° panoramic sensor from visible sensitivity to 8-12 micron sensitivity. A prototype sensor of this type having a 640x480 pixel focal plane has already been developed[20]. Alternatively, it may be possible to mosaic several 640x480 pixel microbolometer focal planes to achieve a similar result. Sensor resolution can be improved by the use of larger focal planes with more pixels[21] and by micro-scanning techniques[22]. A suitable IR-transparent cylindrical window will also be supplied. Protection against small arms fire will be provided in the form of a retractable armor cylinder that can be raised or lowered around the sensor or, alternatively, by elevating the sensor out of a protective well.

The gimbaled IR sensor will be improved by using a second generation FLIR having 1316x480 pixels and dual field of view optics. This sensor is already available on some armored vehicles, and additional vehicles will be receiving it as an upgrade package. If an 8-12 micron 360° panoramic sensor is provided as described above, a second generation FLIR may not be needed if the range of the panoramic sensor exceeds the range of the vehicle's weaponry.

The helmet-mounted display will be improved by upgrading to an 800x600 pixel color flat panel display to increase resolution and to improve color contrast for FBCB2 map information. The higher resolution flat panel display will also have a wider field of view that will add more content to the sensor imagery. The head tracker will be a metal-tolerant magnetic tracker with electronics that fit onto a single card. The single card construction will aid significantly in reducing tracker cost. A prototype of this tracker has been proven effective on an M113 armored vehicle[23], and transition to manufacturing is currently in progress.

The deployed system will include additional image processing functions such as higher sensor resolution, wider display field of view, electronic image stabilization, provision for a second independent viewer of the 360° panoramic camera imagery, and provision for displaying Unmanned Aeronautical Vehicle (UAV) reconnaissance imagery.

Most importantly, the deployed system will be integrated into the vehicle and its systems much more effectively than the prototype system. The STTV sensors will be mounted on the outside of the vehicle in a manner that protects them from abuse and in a location that increases their effectiveness without compromising other vehicle sensors or functions. The STTV controls will be mounted inside the vehicle in a location that is accessible to the commander while he is standing in the hatch or with the vehicle buttoned up. The controls will be integrated with the second generation FLIR sensor controls and the vehicle fire control system so that the hunter-killer teamwork between the vehicle commander and the gunner can be maintained. The STTV helmet-mounted display will be integrated with the FBCB2 tactical terminal and second generation FLIR so that FBCB2 information and second generation FLIR imagery can be displayed effectively and still be controlled properly by the originating systems. Finally, the STTV system will be integrated with new systems still in development for embedded training and embedded maintenance that offer the possibility of reducing vehicle life cycle cost.

Table 2. Improvements envisioned in a deployable STTV system

Function	Prototype System	Deployable system
360° panoramic sensor	Visible sensitivity 8 cameras 5120 (H) x480 (V) pixels acrylic window unshielded	8-12 micron sensitivity 1 camera 8000(H)x500(V) pixels IR-transparent window retractable armor shield
Gimbaled IR sensor	320x240 microbolometer 15.5°(H)x11.5°(V) FOV optics	1316x480 2nd gen FLIR sensor dual narrow & wide FOV optics
HMD display	640x480 monochrome HMD 26°x19° FOV	800x600 color HMD wider FOV
Head tracker	commercial inertial tracker	metal-tolerant magnetic tracker
Image processor	8-slot PVT-200 processor	Next generation PVT processor
Image processing functions	image stitching electronic zoom visible/IR fusion moving target tracking	+ wider display FOV + image stabilization + 2nd viewer + UAV imagery – visible/IR fusion (not required)
Vehicle integration	non-integrated	Sensor integration with vehicle STTV control integration FBCB2 display integration 2nd gen FLIR integration Fire control system integration Embedded training Embedded maintenance

4. STTV SYSTEM APPLICATIONS

The STTV system is designed primarily for turreted armored vehicles, such as the M1 Abrams and the M2 Bradley (Figure 10). It is usually these vehicles that impose the heaviest demands on the vehicle commander's workload. However, non-turreted armored vehicles, such as the M113, are also potential insertion candidates. New armored vehicles currently in development, such as the Crusader, the Future Scout and Cavalry System (FSCS), the Future Combat System (FCS), and the new family of Medium Armored Vehicles are considered to be especially strong candidates for the STTV system. The FCS program has formally identified the need for a panoramic sensor[24,25]. The U. S. Army TACOM has also investigated the use of a panoramic sensor with helmet-mounted display as a see-through turret system for this purpose[26].

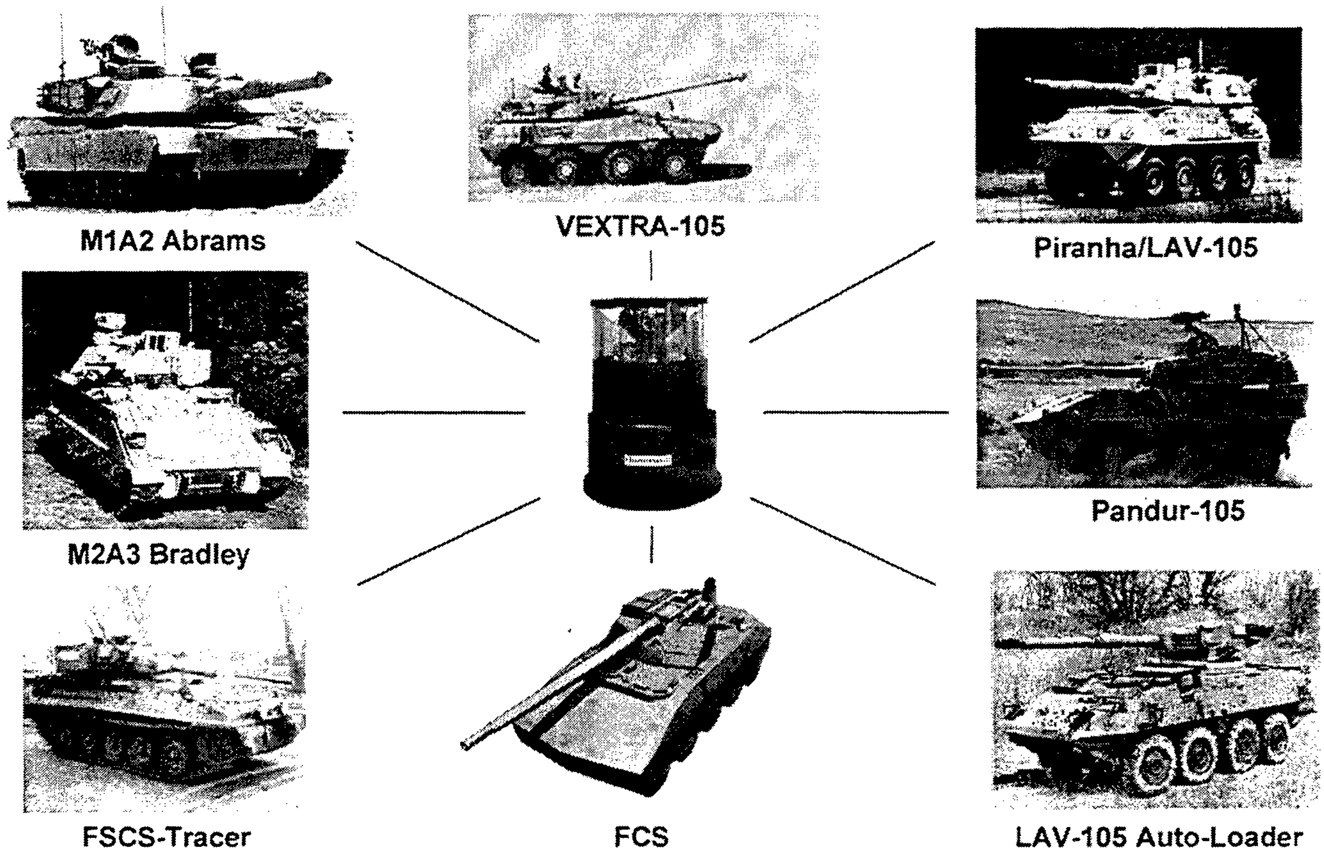

Figure 10. Vehicles identified for STTV insertion

5. SUMMARY AND CONCLUSION

This paper describes the design of a combat vehicle visualization system that provides increased situation awareness to the vehicle commander while seated inside the vehicle or while standing in an open hatch. The system gives the vehicle commander the ability to:

1) detect terrain hazards in the vehicle's path to aid the driver in recognizing hazardous situations that might immobilize the vehicle or cause damage to the vehicle and its crew,
2) detect nearby friendly forces and environmental structures to coordinate movement with other vehicles and to avoid damage to the vehicle, nearby friendly forces, or man made structures,
3) detect nearby ground threats to allow protective responses to be employed,
4) view imagery from the commander's independent viewer while standing in the open hatch,
5) view information on the commander's tactical display while standing in an open hatch to allow immediate notification of incoming reports and to assist in the preparation of outgoing reports without the need to duck back into the vehicle ,
6) view UAV reconnaissance imagery while seated inside the vehicle or while standing in an open hatch.

The system can also be used by a squad leader in the vehicle's passenger compartment as a reconnoitering aid prior to exiting the vehicle for dismounted operations. These capabilities are especially useful at night when the enemy is in the vicinity and when direct vision is impaired because vehicle hatches must be buttoned up and vision blocks must be covered to avoid detection.

The paper describes a prototype system that demonstrates essential system features using existing components to reduce development cost. Improvements envisioned for a deployable system are discussed. Finally, vehicle insertion opportunities are identified.

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List of Symbols, Abbreviations, and Acronyms

AFATDS	Advanced Fire and Tactical Distribution System
AGS	Armored Gun System
AMEL	Active Matrix Electro Luminescent
AMTT	Advanced Metal Tolerant Tracker
APC	Armored Personnel Carrier
ATD	Advanced Technology Demonstration
AUSA	Association of the United States Army
BAA	Broad Agency Announcement
BC	Bradley Commander
BCIS	Battlefield Combat Identification System
BCV	Bradley Command Vehicle
BFIST	Bradley Fire Support Team
BFISTV	Bradley Fire Support Team Vehicle
C2V	Command and Control Vehicle
CCD	Charge Coupled Device
CDU	Commander's Display Unit
CID	Commander's Integrated Display
CIV	Commander's Independent Viewer
CITV	Commander's Independent Thermal Viewer
CTD	Commander's Tactical Display
CVC	Combat Vehicle Crew
CWS	Commander's Weapon Sight
DARPA	Defense Advanced Research Projects Agency
DDC	Day Display Component
DID	Driver's Integrated Display
DSP	Digital Signal Processor
DVE	Driver Vision Enhancer
FBCB2	FXXI Battle Command Brigade and Below
FCS	Future Combat System
FCV	Future Combat Vehicle
FISTV	FIre Support Team Vehicle
FLIR	Forward Looking Infra Red (Sensor)
FOR	Field of Regard
FOV	Field of View
FSCS	Future Scout and Cavalry System
FXXI	Force 21
$FXXIC^2$	Force 21 Command and Control
GCDP	Gunner's Control and Display Panel
GDLS	General Dynamics Land Systems
GITS	GMHE Integrated TOW Sight
GPS	Gunner's Primary Sight
GPS	Global Positioning System
HDTV	High Definition Television
HMD	Helmet Mounted Display
HMMWV	High Mobility Multi-Wheeled Vehicle
HMWWV	High Mobility Multi-Wheeled Vehicle (common mis-spelling)
HTI	Horizontal Technology Integration
Hz	Hertz
IBAS	Improved Bradley Acquisition System
ICCD	Intensified Charge Coupled Device
ICCS	Integrated Command and Control System
IDATT	Integrated Display and Tactical Terminal (color)

IHADDS	Integrated Helmet And Digital Display System
IHAS	Integrated Helmet Assembly Subsystem
IPD	Inter-Pupillary Distance
IR	Infra-Red
ITAS	Improved Target Acquisition System (SGF)
IVIS	Inter Vehicular Information System
JCIT	Joint Command Information Terminal
LAV	Light Armored Vehicle
LRIP	Low Rate Initial Production
MEMS	Micro Electro Mechanical System
NBC	Nuclear Biological Chemical
NETD	Noise Equivalent Temperature Difference
NFOV	Narrow Field of View
NVESD	Night Vision and Electronic Sensors Directorate
ODS	Operation Desert Storm
ONR	Office of Naval Research
PVSI	Panoramic Vision Systems Incorporated
RAM	Random Access Memory
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SGF	Second Generation FLIR
SEP	System Enhancement Program
SID	Society for Information Display
SIMNET	Simulation Network (DARPA)
SIP	System Improvement Program
SLID	Small Low-Cost Interceptor Device
SPIE	Society of Photo-Optical and Instrumentation Engineers
STTV	See-Through Turret Visualization
SVGA	Super Video Graphics Adapter (800x600 pixels)
TACOM	Tank Automotive and Armaments Command
TARDEC	Tank Automotive Research Development and Engineering Center
TBD	To Be Determined
TOW	Terminally Optical Wire-Guided
TWS	Thermal Weapon Sight
UAV	Unmanned Aerial Vehicle
UDLP	United Defense Limited Partnership
VGA	Video Graphics Adapter (640x480 pixels)
WFOV	Wide Field of View
WRAP	Warfighter Rapid Acquisition Program